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A FRAMEWORK FOR THE DEVELOPMENT OF IMPROVED TACTICAL SYMBOLOGY

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The utility of symbology would be increased by making it more compatible with current and emergent tactical doctrine. A structured methodology based on a role-playing exercise was developed for eliciting graphically related tactical information requirements from experienced military tacticians.

The method, involving a 2-stage

The ~~methodology, involving a two-stage~~ elicitation process, ~~employs~~ uses doctrinally-sanctioned information-processing guidelines to prompt participants to generate task-related tactical questions (e.g., What is the principal (over)

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deficiency of a specific enemy unit?) and candidate answers (e.g., mobility, personnel). A pilot test used two experienced staff officers and a European defensive scenario. The numerous question and answer sets obtained were organized into 22 clusters (i.e., data structures), with each one specifying questions in decreasing order of detail according to a common tactical theme (e.g., immediate threat, enemy vulnerability, priority targets). These data structures represent categories of task-based information requirements which can serve as potential building blocks in the development of a dynamic, flexible database for tactical symbology.

The framework also contains a preliminary analysis of symbol design effectiveness based on a taxonomy of basic information-processing behaviors, which include symbol discrimination, display search, and symbol learnability. Each of these processing components was used as a focus for examining relevant research literature and its implications; and as a result, preliminary guidelines were derived for improving symbol design effectiveness (e.g., minimize the amount of feature similarity among different members of a symbol set). Finally, to help monitor future symbology development efforts, a multi-faceted evaluation strategy is outlined which calls for systematic attention to content-based, and tactical performance-based assessment criteria.

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A FRAMEWORK FOR THE DEVELOPMENT OF IMPROVED TACTICAL SYMBOLOGY

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FOREWORD

The Human Factors Technical Area of the Army Research Institute (ARI) is concerned with aiding users and operators to cope with the ever increasing complexity of the man-machine systems being designed to acquire, transmit, process, disseminate, and utilize tactical information on the battlefield. The research is focused on the interface problems and interactions within command and control centers and is concerned with such areas as topographic products and procedures, tactical symbology, user-oriented systems, information management, staff operations and procedures, sensor systems integration and utilization, and issues of system development.

The current symbology, as provided in FM 21-30 and FM 21-21, is widely agreed to be inadequate. As a result, a number of Army agencies are working to evolve special sub-sets of new or modified symbols that are better suited to their particular information-processing needs. In the absence of a common frame of reference, these efforts could result in a proliferation of specialized symbols that meet the needs of some, but not all, potential users. The present publication tries to identify and categorize the situational, information, and behavioral factors that contribute to the effective design and use of visual symbols for representing the battlefield. This analysis is a necessary first step in the development of a comprehensive framework, typology, and theory of tactical symbology.

Research in the area of tactical symbology is conducted as an inhouse effort augmented through contracts with organizations selected for their specialized capabilities and unique facilities. The present study was conducted by personnel of Perceptronics, Inc., under Contract DAHC19-78-C-0018. This research is responsive to requirements of Army Project 2Q762722A765 and related to special requirements of the Combined Arms Combat Developments Activity, Fort Leavenworth, Kans. Special requirements are contained in Human Resource Need 78-98, Graphic Symbology for Automated Tactical Displays and 78-150, Optimizing Display of Topographic and Dynamic Battlefield Information.

Joseph Zeidner

JOSEPH ZEIDNER
Technical Director

A FRAMEWORK FOR THE DEVELOPMENT OF AN IMPROVED TACTICAL SYMBOLOGY

BRIEF

Requirement:

To improve the effectiveness and enlarge the scope of the symbology used to represent tactically significant objects and/or events on the battlefield.

Procedure:

In order to develop a comprehensive framework for defining symbology issues, an analysis was performed to identify task-based information requirements. The analysis was based on four basic task dimensions consisting of (1) a user category--i.e., command group, combat support staff, and service support staff; (2) a task category--i.e., assessment, planning, and tactical communications; (3) a military operations category--i.e., offense, defense retrograde, and special operations; and (4) an information category--i.e., enemy situation, and terrain/weather.

Findings:

The task-based information analysis was demonstrated to be an effective means for eliciting from experienced tacticians many of the "questions" important to battlefield command and control operations. These questions were categorized into three types: (1) those amenable to expression via current symbology; (2) information deficiencies--i.e., tactical questions which current symbology has failed to answer; and (3) information imperatives--i.e., new questions which will require new types of symbolization.

Utilization of Findings:

The products of this analysis will contribute to a methodology which will aid in the development of new or modified tactical symbols that portray the status of the battlefield more completely and understandably.

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A FRAMEWORK FOR THE DEVELOPMENT OF IMPROVED TACTICAL SYMBOLOGY

1. SUMMARY

1.1 Statement of the Problem

The use of military symbols dates back at least to the days of Napoleon. Warfare has changed since that era and so have the methods by which the battlefield environment is graphically portrayed. Yet the symbology used to portray the tactical situation has remained the same for decades. The following question therefore emerges: Is conventional symbology adequate to meet the tactical needs of today's user? Conventional symbology (as represented in Army Field Manual 21-30, Military Symbols) has been criticized for such reasons as: the level of detail is often inappropriate; the details of the code are hard to remember; the extraction of salient information is difficult; and, the adaptation to automated displays is cumbersome and inefficient. Consequently, there seems to be a widespread concensus that the mechanics and utility of the current symbol system are being severely strained by the increasing volume and complexity of tactical data.

Fortunately, modern electronic storage and display systems are now available that may significantly reduce this information processing burden. In particular, it is now possible to look forward to the development of improved symbology that is expressly designed to exploit the advantages of computer technology. Whereas conventional symbology is static in nature--requiring a one-to-one mapping of symbol-to-concept, improved and new types of symbology may be dynamic--permitting the form and content of symbols to change in response to changing user requirements. Consonant with this increase in information processing power and display, modern symbology may come to assume a larger role in tactical assessment and planning. Thus, to set the stage for these new developments, this report attempts to establish a framework for considering the relevant issues and requirements as well as the design and evaluation principles surrounding improved, user-oriented tactical symbology.

1.2 Technical Approach

1.2.1 A Framework for the Development of Improved Symbology. The development of a symbolic language for communicating tactical information entails the specification of the tactical database (content) as well as the identification of perceptually effective design criteria (form). Our perception of the components in the development process and their interconnectedness are illustrated in Figure 1-1. The organization of this report begins with a discussion of selected issues that point to needs and directions for improving tactical symbology (Chapter 2). The derivation of the content or information requirements of tactical symbology is then the subject of a prototypical, task-based analysis described and pilot-tested in Chapter 3. A complementary behavioral analysis of design criteria for effective symbology follows in Chapter 4. Finally, evaluation procedures are required to monitor the progress of development efforts; Chapter 5 describes a diversified set of assessment criteria for evaluating the adequacy of information content, the effectiveness of symbol design, and the impact of symbology on tactical decision making. The following paragraphs provide a brief summary of the objectives and methodology for each area of program effort. The reader is referred to appropriate chapters of this report for a detailed discussion of each topic.

1.2.2 Tactical Symbology: Selected Issues and Analyses (Chapter 2). Emerging doctrine and advancing technology call for the development of improved tactical symbology. Although conventional symbology (FM 21-30) can convey basic unit information (e.g., identity, function, size and weapon type), it cannot communicate a richness of detail

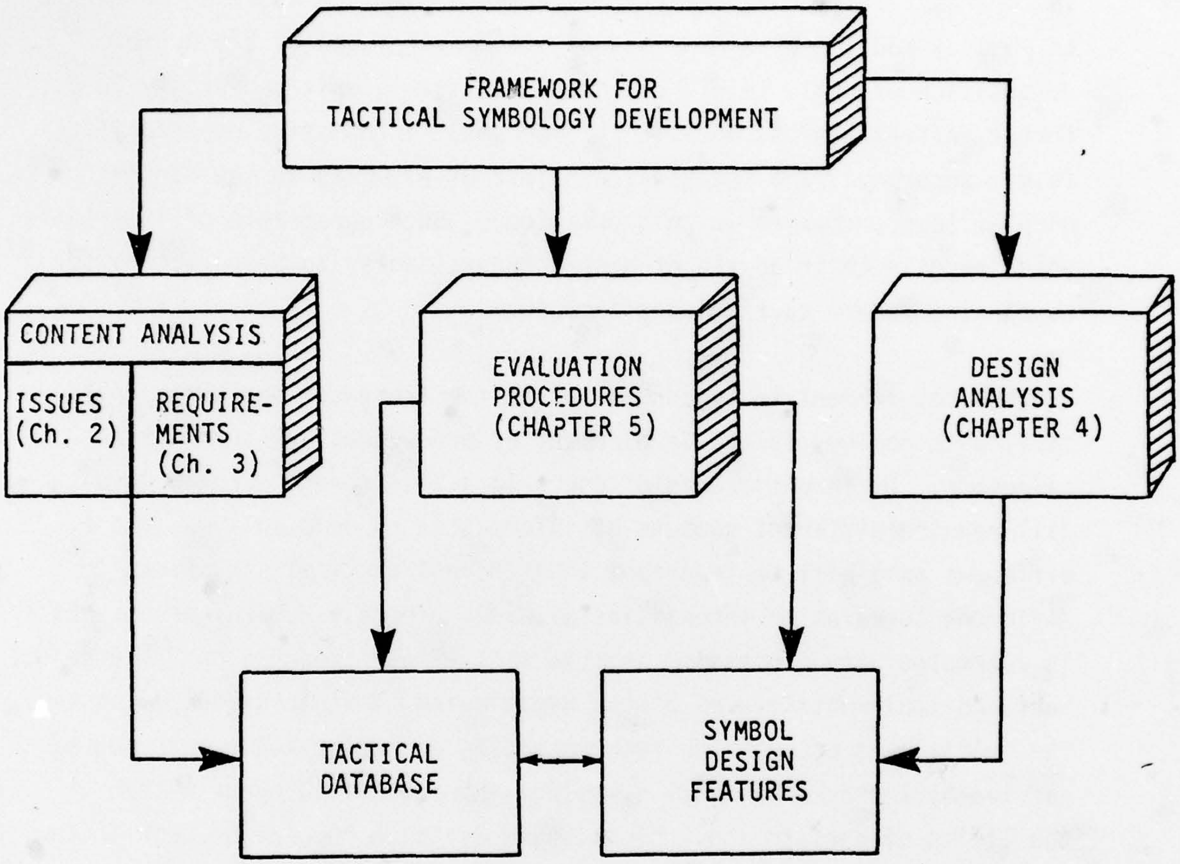


FIGURE 1-1. A FRAMEWORK FOR THE DEVELOPMENT OF TACTICAL SYMBOLOGY

considered important by command personnel, and it cannot accommodate most of the new "imperatives" of tactical doctrine (e.g., FM 100-5, Operations). In contrast, an improved tactical symbology seems to require the ability to portray additional dimensions of information such as the dynamic composition of units (e.g., combined-arms team), unit capability (e.g., threat, effectiveness, mobility, firepower), information dependability (e.g., accuracy), and the updated nature of elements in the current display (e.g., changes in unit position). Such parameters of information, which vary in their degree of abstractness, appear to be necessary for supporting modern tactical performance.

Another requirement to be considered in the framework for an improved tactical symbology is the development of procedures for information selection. Different groups of users (e.g., different echelon levels) will require different subsets of information to be displayed, and different data will be important in different tactical situations (e.g., different terrains or intensities of war). In this regard, advancements in automated data-processing systems will likely impact upon the development and implementation of a more dynamic and flexible symbology system. The fulfillment of both the representation and selection requirements carried by improved tactical symbology, however, must occur within the limits of certain constraints, such as those imposed by user acceptance, and interservice and international (i.e., NATO) standardization.

1.2.3 A Query-Based Methodology for Content Analysis (Chapter 3). One of the most basic ingredients of symbology development should be the expansion of a tactical database (i.e., organized set of information requirements) to accommodate both the emerging principles of tactical doctrine (e.g., FM 100-5) and the increased precision and range of modern weaponry. With this goal in mind, a formal methodology was developed for eliciting candidate information requirements from experienced military tacticians. The approach addresses the problem of elicitation and data analysis in the context of a structured role-playing exercise. In essence, doctrinally-sanctioned information processing guidelines are used as "prompts" to elicit candidate requirements (e.g., FM 100-5 states "Concentrate on the critical times and places"). Each prompt is embedded within a tactical scenario and presented, one at a time, to participants in the elicitation exercise. They are instructed to generate tactical questions which if adequately answered, would permit them to comply in full with doctrinal requirements. The implicit goal of this procedure is to insure a correspondence between the functional context in which symbology is used and the semantic content it offers the user. In other words, we are suggesting that under ideal circumstances improved tactical symbology should provide battlefield decision-makers with accurate and timely "answers" to complex tactical "questions."

Thus, deciding what information to include in improved symbology might perhaps be approached by deciding what questions it should be able to answer. Specifically, the process of question generation seems to represent a more straight-forward and less ambiguous task than the direct elicitation of lists of information requirements. Most likely, this is because some form of self-interrogation always intervenes, either covertly or overtly, when individuals try to identify their information "requirements." Once a question is generated, it can then be used as a prompt in a second elicitation task designed to identify the range of possible "answers." The result of this follow-up elicitation is a set of tactical concepts corresponding to candidate information requirements (i.e., response categories). For example, a doctrinal prompt might elicit the follow tactical question: *What is the principal deficiency of a specific enemy unit?* Later, this query would be used as an elicitation prompt to generate a set of possible answers (e.g., *Mobility, POL, Ammo, Personnel, Morale*).

Following an in-depth discussion of the two-stage elicitation method for identifying information requirements, Chapter 3 describes an exploratory study in which the feasibility of the technique was tested. Two experienced Army staff officers participated in the study. In the context of a tactical scenario involving command group decision making for defensive operations in rural terrain, they were asked to generate task-related questions in response to situational and doctrinal prompts. The resulting questions were then used to facilitate the elicitation of corresponding information requirements (i.e., potential answers to relevant questions).

The preliminary study was also intended to illustrate the important role of data organization in efforts to develop an accessible database for improved symbology. After being reduced and analyzed, the numerous tactical questions elicited in the study were organized into a set of 22 clusters of questions (i.e., data structures), with each one reflecting a different tactical theme. The data structures are task-oriented and are designed so that they can be selectively accessed for retrieval of information at different levels of tactical detail. For example, consider the cluster of questions referring to "Type of Threat". Under certain circumstances, the user may only have time for a quick overview of the situation--all combat-type vs. all support-type units. In another context, the user may wish to conduct a more elaborate analysis by selecting finer levels of information detail (e.g., by asking for "unit composition" or "special weapons"). In effect, each data structure represents a task-based category of information requirements which can serve as a potential building-block in the development of a dynamic database for tactical symbology.

Each tactical question in the database, therefore, can be answered at different levels of specificity ranging from abstract and summarized to concrete and detailed. By restating questions at different levels of abstraction, the dimension of information summarization was explicitly built-in to the content analysis. The overall objective was to generate a set of representative information requirements for symbology, and, in the process, illustrate the applicability of a task-based technique for expanding current conceptual foundations.

1.2.4 <u>A Behavioral Analysis of Symbol Design Effectiveness (Chapter 4)</u>. To insure the usefulness of a tactical symbology which meets the challenges of modern informational requirements, the performance context in which the symbology is to be used should be examined. Toward this end, a general taxonomy of fundamental behavioral requirements was developed through analysis of a task scenario. The task analysis suggested that the process of using symbols has three basic components: discrimination, search, and learnability (symbol acquisition and retention). This taxonomy was then used to organize available behavioral research literature in order to derive some preliminary guidelines for symbol design. Specific guidelines were offered toward the development of symbols which facilitate the performance of each of the behavioral processes, for example:

<u>Discimination</u>

Minimize, to the extent possible, the amount of feature similarity among different numbers of a symbol set.

<u>Search</u>

Minimize the visual saliency of those features that must remain redundant across members of a symbol set.

Learnability

> *Take advantage of the user group's prior learning and conditioning to select symbol design features (e.g., iconicity, color) which enhance association formation. For example, if the color "red" is culturally identified with the concept of danger, it might be utilized in the portrayal of enemy threat.*

Overall, such guidelines are intended to help support future symbol design efforts by codifying and applying some relationships between design variables and user-based performance criteria.

1.2.5 Toward Evaluating the Effectiveness of Tactical Symbology (Chapter 5). The objective of this chapter is to establish a preliminary set of assessment procedures for evaluating the effectivness of new symbology. Three major categories of assessment criteria were identified: (1) Content-based criteria--standards for evaluating the functional breadth and information depth of a candidate tactical database; (2) User-based criteria--procedures for evaluating the discriminability, searchability and learnability of proposed symbol designs; (3) Tactical criteria--a set of task-based procedures for assessing the impact of symbology on tactical problem-solving and decision-making. This multi-criteria approach carried out in a logical sequence provides an evaluation framework to support the development and improvement of tactical symbology.

2. TACTICAL SYMBOLOGY: SELECTED ISSUES AND ANALYSES

2.1 Overview

The contents of this chapter reflect the position that an improved tactical symbology is necessary primarily to meet new user requirements that accompany emerging tactical doctrine and advancing technology. Consistent with this view, Sidorsky, Gellman, and Moses (1979) have developed the following definition of tactical symbology that emphasizes command functions:

> *"Tactical symbology refers to the symbols used to portray the information acquired, manipulated, and displayed by a Tactical Operations Center (TOC) in supporting the on-line information needs of a commander engaged in planning and/or conducting a combat operation."*

In this chapter, a discussion of requirements for an improved symbology is preceded by a brief description of the limited breadth of conventional symbology. The requirements are then elaborated and examined in the context of implementation issues for improved symbology, such as symbology standardization and user acceptance.

2.2 Conventional Symbology

Conventional symbology (as documented in Army Field Manual 21-30, Military Symbols) has traditionally served a communication function (who, what, and where) and for this purpose its content or "database" may, in fact, be adequate. When used in conjunction with a battlefield situation display, conventional symbology addresses a number of important tactical questions. A representative list of these, presented in Table 2-1, was generated by reviewing FM 21-30 in consultation with the military members of our research team. This list suggests that conventional symbology is

TABLE 2-1

TACTICAL "QUESTIONS" FOR CONVENTIONAL SYMBOLOGY

1.	*What types of enemy units oppose me?*	(Infantry, Armor, etc.)
2.	*What is their identity?*	(101st Battalion, etc.)
3.	*Where are they located?*	(Precise or actual location, future or proposed location)
4.	*What size are they?*	(Division, Battalion, etc.)
5.	*What kind of mobility do they have?*	(Foot mobile, Airborne, etc.)
6.	*Where are their command posts?*	(Present or actual location, future or projected location)
7.	*What operating boundaries exist?*	(FEBA, rear boundaries)
8.	*What control measures are known?*	(Contact points, linkup points, release points, start points, delay lines, fire coordination line)
9.	*What is their principal weapon system?*	(Recoilless Rifle, Mortar, Howitzer, air defense machine gun)

capable of conveying the basic information required for coordinating and supervising battlefield operations (i.e., unit size, identity, and function).

Perhaps the most obvious problem with the content of conventional symbology is the narrow range of tactical concepts it can accommodate. In this regard, Sidorsky (1977) comments:

> *"The current military symbology of FM 21-30 is a very efficient method for describing the administrative make-up of a unit. A lot of information about the composition of the unit can be packed into a small space. Unfortunately, however, most of this information is of little direct value to the processes of situational analysis, problem solving, decision making and other higher level cognitive activities associated with command and control. The current symbology does a good job of identifying a unit but it doesn't tell anything about the unit's actual status or capabilities."*

Several problems related to the issue raised by Sidorsky are discussed in detail in the following sections which focus on the development of improved tactical symbology.

2.3 Toward Improved Symbology

This section describes selective issues that appear worthy for consideration by any program designed to develop improved tactical symbology. These issues have been divided into two major classes - information content and information selection.

2.3.1 Information Content. To improve the efficiency of battlefield operations, a new symbology should have the capability to represent the combined-arms composition of friendly and enemy units, the functional combat capabilities of these units, the probable accuracy of the battlefield intelligence portrayed, the updated nature of battlefield information, and critical aspects of the terrain. Each of these issues is discussed here, followed by a brief look at the challenges offered by recent advances in military technology and doctrine.

Combined Arms Forces. Current U.S. Army tactical doctrine (FM 100-5, Operations) favors the use of a combined arms force. A combined arms force can be defined as "a team of two or more arms, each supplementing the other's capabilities, to accomplish an assigned mission" (U.S. Army Reference Book 100-7, The Common Languages of Tactics). More specifically, it has recently been written (Hardy, Patrick, and Georgian, 1976):

> *"...common practice is to take a tank company and attach it to an infantry battalion and take a company from that infantry battalion and give it back to the tank battalion. The resulting combined arms force then still has three line companies, but, to distinguish it from its un-cross-attached form, it is generally referred to as a task force. There is nothing rigid in the one-for-one exchange idea. What units are cross-attached and how they are cross-attached is determined based on the tactical situation. The one-for-one system is the most common and the resulting task force would be designated tank-heavy or infantry-heavy, depending on whether there are more tank or infantry companies in the task force. ...As the system is envisioned, it is quite possible for a tank battalion to actually end up an infantry-heavy task force."*

Thus, in keeping with emerging tactical doctrine, a basic requirement of tactical symbology is that it accurately portray the current functional character of a military unit.

An underlying assumption of conventional symbology (FM 21-30) is that a military unit is relatively homogeneous with respect to function. For example, an armored unit is assigned a specific symbol to distinguish its function from that of the infantry. With the advent of combined arms, however, the assumption of fixed unit function is now open to question. The problem is that dynamic cross-attachment destroys the functional integrity of a military unit. For example, consider two fictitious battalions described in Figure 2-1. Each is intact and consists of three line companies. When fielded, however, each battalion may assume a dramatically different functional character. Consider the same two battalions with cross-attached units as described in Figure 2-2. The 3rd Tank Battalion when fielded is functionally an infantry unit, while the 5th Infantry Battalion is functionally an armored unit. Each battalion retains its original designation, however, despite its change in functional status. This practice can be referred to as the historical approach to symbolic portrayal. The underlying assumption is that the origin of a unit is more important to portray than its current functional capability.

The symbolic portrayal of historical function increases the information processing burden on the symbol user by requiring him to "update" symbols prior to interpreting their tactical significance. If the historical approach is continued, the amount of preprocessing required to interpret a situation display will necessarily increase as the use of combined arms tactics becomes more prevalent. The impact of cross-attachment can, however, be minimized by simply reassigning unit designations as required to match current unit function. Unit identification, required to establish chain of command, would of necessity be represented by means other than a function or duty symbol.

The symbolic portrayal of historic vs. current unit function represents a procedural issue which has long range implications for developing improved symbology as well as immediate implications for conventional symbology. Existing unit symbols can be reassigned under dynamic battlefield conditions to portray current functional status without any changes in actual graphic

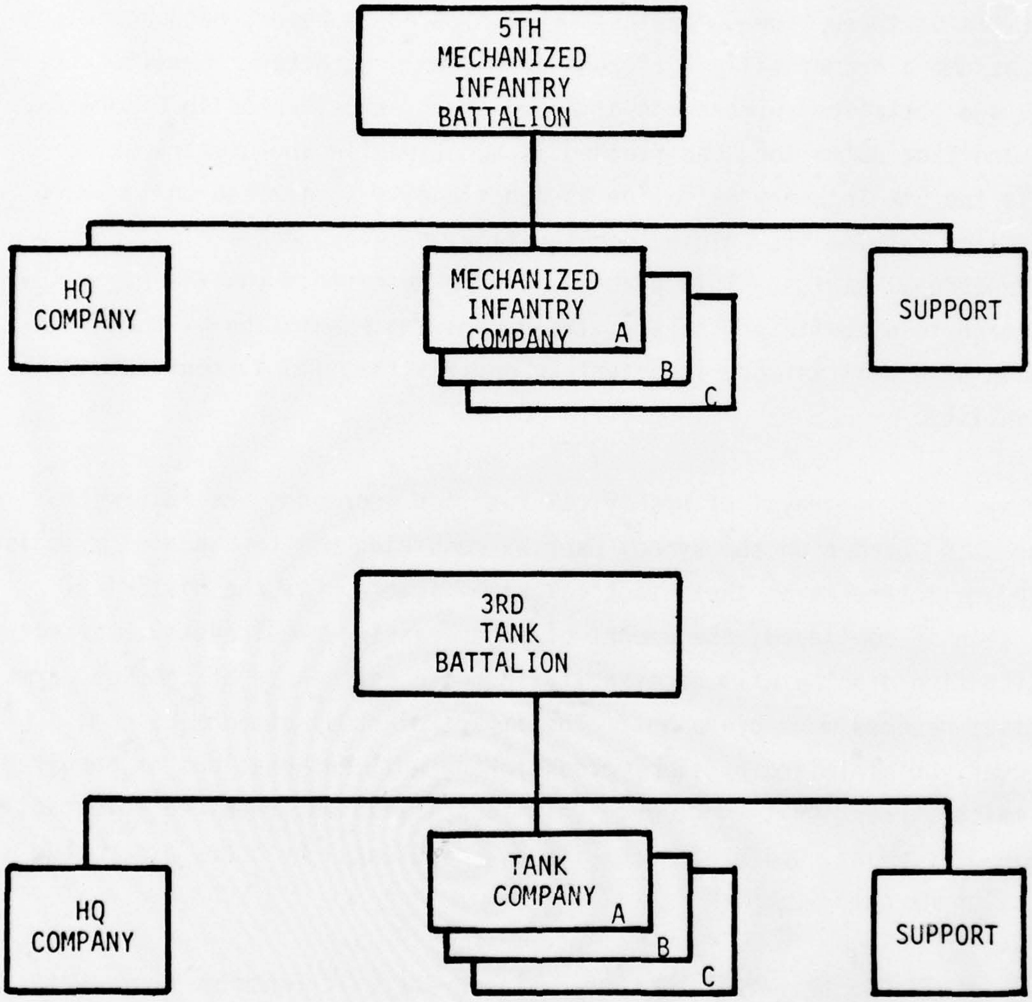


FIGURE 2-1. BASIC UNIT STRUCTURE

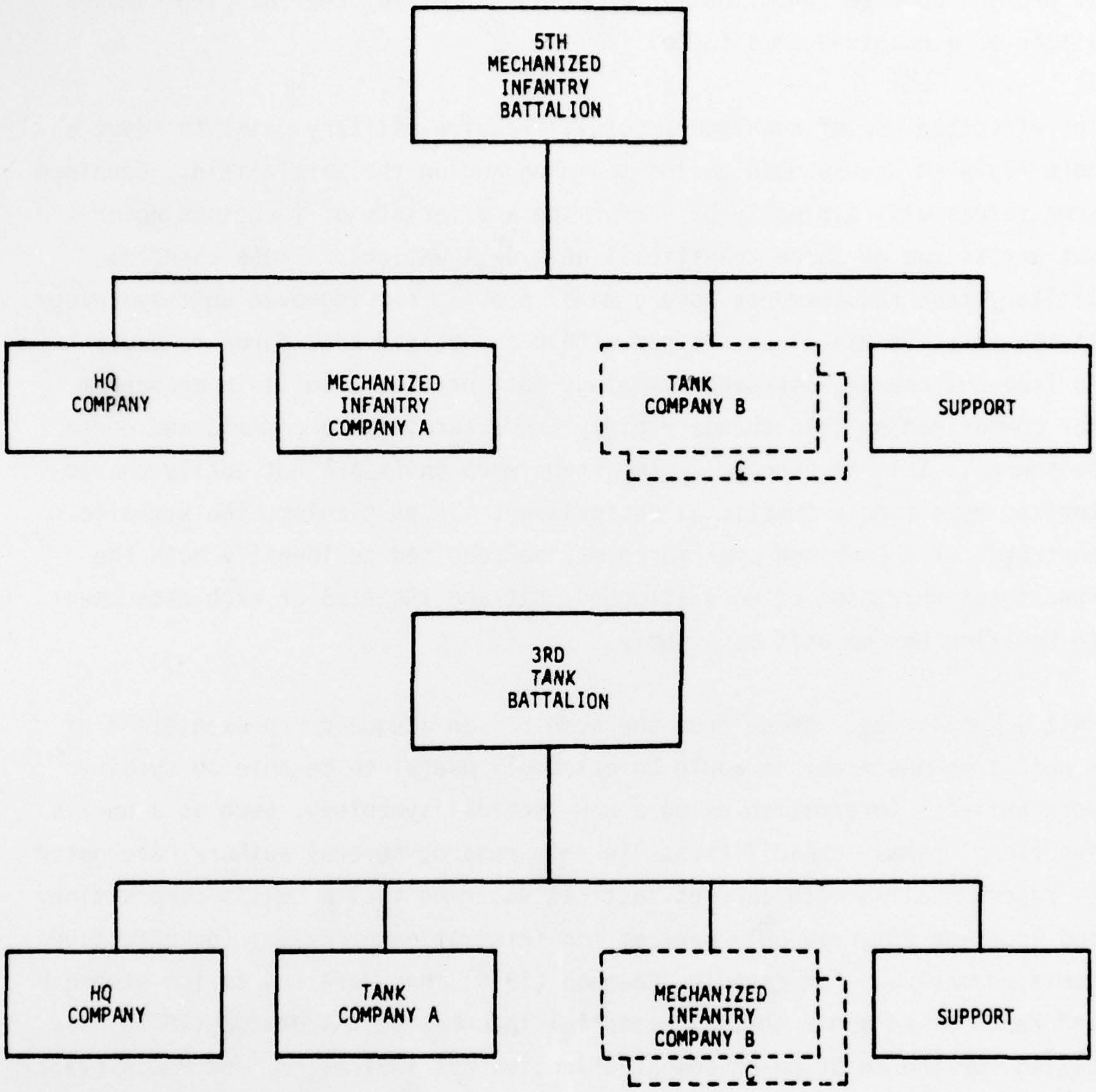


FIGURE 2-2. CROSS-ATTACHED UNIT STRUCTURE

design. Similarly, a major requirement of improved symbology may be that it provide updated functional information to reflect the changing composition of a combined arms force.

The effective use of combined arms will require military units to adopt a more fluid structure both during training and on the battlefield. Combined arms forces will typically be performing a diveristy of functions which cut across two or three traditional unit designations. These changing military task requirements pose a major problem for improved unit symbology. If the relative mix of unit types within a combined arms force is prone to frequent change, improved symbology must provide a built-in mechanism for communicating this change rapidly and accurately to command and control personnel. This is especially important when units are not easily characterized by a single functional designation. In particular, the symbolic portrayal of a combined arms force may be required to identify both the functional character of each attached unit and the size of each attachment in relation to the unit as a whole.

Unit Capabilities. Aside from the need for an adequate representation of a unit's composition, it would be extremely useful to be able to specify more abstract information using a new tactical symbology, such as a unit's functional combat capabilities. In this regard, several authors have noted in papers dealing with current tactical doctrine that a unit's composition and location comprise only part of the information necessary for effective decision making. For example, Channon (1976), has referred to the strength and reach of an enemy unit as essential information, Middleton (1977a) has called for the adoption of combat effectiveness indicators, and Moses (1977) has stated that a unit's threat value should be represented in a new display symbology.

Since FM21-30 symbology cannot represent unit capability directly, capability information must be inferred. For example, a brigade commander can infer that he is at a disadvantage if he is facing two enemy divisions. The same commander may in fact be in a superior position to the enemy if he is defending a narrow pass with fresh troops against an enemy who has suffered high casualties attacking the pass over a number of days. Neither of these situational and dynamic tactical information scenarios can presently be displayed. A new system might relieve some of the enormous burden placed on commanders' memories, but such a capability, of course, remains to be demonstrated.

The issues concerning the graphic portrayal of unit capability information can be discussed in terms of the types of requirements that a capability symbology might fulfill. Such requirements have been put forth by different writers and they can be conveniently presented in the form of specific tactical questions. In addition, suggestions have been made for how the graphic representation of unit capability information might be approached.

For example, Channon (1978) has provided the following as key questions in determining what's important about the capabilities of an enemy unit:

(1) Is it a <u>striking</u> unit?
(2) How <u>powerful</u> is it?
(3) With what <u>force</u> and <u>range</u> can it strike?
(4) Is it <u>moving</u> now?
(5) Is it <u>changing</u> its structure (e.g., assembling into a combined arms formation)?

Channon considers these questions to be so important that they should take precedence over other related information requirements such as, for example, order-of-battle details.

Sidorsky (1977) has proposed a specific list of eight tactical variables that might be included in the portrayal of unit capability information. These can be phrased in question format as follows:

(1) Threat. What is the overall tactical threat posed by an enemy unit or what is the overall capability needed by a friendly unit to counter enemy actions?

(2) Effectiveness. What is the combat readiness of enemy and friendly units? This includes such factors as combat experience, training, fatigue, morale, exposure, etc.

(3) Mobility. How mobile are friendly and enemy units? This variable includes mobility factors inherent to the unit such as motor and air transport as well as the available road network, obstacles, minefields, etc.

(4) Firepower. What is the sum total of a friendly or enemy unit's available direct and indirect operational weaponry than can be employed in accomplishing the mission?

(5) Logistics. What is the relationship of the unit to its source(s) of essential supplies at the present time or at some future time predicated on an assumed scenario of future action?

(6) Terrain. What tactical advantage/disadvantage does a unit have as a result of the terrain it occupies and/or as a result of probable avenues of approach and/or maneuvering area?

(7) Support. To what degree can a given unit be supported by other elements such as artillery coverage, protected flanks, air support (fixed wing or helicopter, radar coverage, communication services, etc.)?

(8) Density. How massed or dispersed are a unit's elements and as a result, what is a unit's ability to launch or withstand either a conventional or nuclear attack?

Although the sets of questions pointed to by Sidorsky's scheme differ in scope and specificity from those generated by Channon, both writers have the same goal in mind -- namely, to focus attention to the need for graphic portrayal of directly usable unit capability information. Given the conceptual overlap between the two sets of questions, when taken together they raise significant issues concerning what type of capability summary should be conveyed to the user.

Toward the graphic representation of responses to unit capability questions, Channon (1978) has suggested certain design features that he thinks modern tactical symbology should have. Some of the features that might be included in his system are the following:

(1) figurative symbols which would mimetically reflect unit type (e.g., a tank silhouette to portray a tank unit).
(2) a "size is strength" concept so that if a unit is powerful, it is visually shown as bigger and/or brighter.
(3) a "dynamic movement line" so that if a unit is on the move, it can be depicted as moving in the direction reported.
(4) a "combined arms indicator" so that units determined to be operating with a combined arms framework at a recognized greater strength will be so represented.
(5) a "striking reach indicator" (e.g., vector) so that a unit's shooting range is made immediately obvious.

(6) an "optional OB display" so that alpha-numeric information (e.g., unit identification number) can be displayed on call.

These features are all designed in the spirit of overcoming apparent shortcomings with current symbology, that is that the FM 21-30 symbols are abstract, of uniform size, static, restricted to single-unit function description, and cluttered with numerical designators.

Another innovative approach to the graphic portrayal of the degree of real or perceived unit capabilities has been proposed and developed by Sidorsky (1977). He has recommended the design of a "doughnut" symbol with eight different positions on the doughnut representing each of the eight capability descriptions, respectively. The positions are spaced according to clock positions at 90 minute intervals, i.e., 1200 hours, 1300, 1500, 1630, 1800, 1930, 2100, and 2230. At each position five different strength levels from "very high" to "very low" can be represented. Thus, a single symbol can portray, for example, a unit which has a "high" level of overall threat, a "normal" level of effectiveness, a "very low level" of mobility, etc. Sidorsky's prototype symbology includes other features such as the typing of unit size (echelon) and the grouping of individual units; however, its effectiveness for communicating unit capability information remains to be empirically demonstrated.

The importance of representing unit capability graphically is evidenced by the fact that researchers in the field are already proposing ways toward meeting the challenge. However, at the present stage of symbology development, the work of Channon (1978), Sidorsky (1977) and others (e.g., the USAICS group effort on Combat Power Symbology) is more significant in terms of the information requirements that they set down for unit capability rather than for their specific graphic recommendations of how the information might be portrayed.

Information Dependability. Much of the information stored in a tactical data base is inevitably less than perfectly trustworthy (i.e., accurate reliable, creditable, and the like). That is, data may not be valid in the sense that they do not validly represent the true state of the world (Samet, 1975). This phenomenon results from a variety of reasons ranging from the time-lag between data observation and data availability of errors and inaccuracies in the way the data is observed, collected, transmitted, processed, stored, etc. Whatever the source of data fallibility, however, there is no doubt that it should have a very definite impact on how the data is interpreted and converted into usable information (e.g., Johnson, Spooner, Cavanagh, and Samet, 1973). In this regard, Halpin, Moses and Johnson (1978) found that one-half of the variability among analysis in assigning qualitative ratings to intelligence reports can be attributed to perceived differences in the truth value of the reports. No other factor (such as importance, clarity, scope, expectedness, and threat) could account for more than about one-quarter of the variance. Therefore, an important issue becomes whether it would be desirable to graphically portray data validity parameters; and, if so, effective ways must be sought to graphically portray such information.

An issue closely related with that of the evaluation of data dependability concerns the apparent consistency of data. Are the data under evaluation or interpretation consistent with known states, events, trends, motives, etc.? Does confirming or highly correlated data exist? Are the data contradicted by other accepted data?...Answers to such questions have become easily manageable by recent advances in the development of relational data management systems, including for example, the conceptual design of MIQSTURE, an experimental online language for ARMY tactical intelligence information processing (Katter, 1978). However, again, the issue becomes whether it would be desirable to graphically portray the respective answers to questions of data consistency; and, if so, how might such graphic portrayal be approached?

Updated Information. Tactical decisions consistent with a rapidly changing battlefield situation require attention to a succession of events, as opposed to a static view of the current composition and position of friendly and enemy forces. Considering the recent technological advancements in military operations, it is conceivable that the need to keep track of the dynamic aspects of a battlefield may tax the decision maker's cognitive abilities. Consequently, it would be useful to portray graphically recently updated information as such on tactical battlefield displays.

Vicino, Andrews and Ringel (1965) found that even though extracting and assimilating changes in the battlefield situation should be more difficult as the amount and extent of battlefield alteration is increased, this degradation of performance can be reduced by increasing the saliency of updated symbolic information of the revised battlefield replica. In this regard, multiple cues were clearly superior to unitary cues. One complication not addressed by these authors is that if certain symbolisms are used to denote updated information, this reduces the number of available symbol types that can be manipulated to represent other information, such as the qualitative and quantitative attributes of combat forces. One alternative possibility would be to use flash coding to draw attention to recently altered information, such as that used in displays designed to facilitate tracking performance (Ziegler, Reilly and Chernikoff, 1966) or that used in the Map-Scholar system to focus a student's attention on relevant map information (Collins, Adams and Pew, 1976).

New Technology. The content of improved symbology, apart from redressing past deficiencies, requires expansion to accommodate new tactical doctrine and modern weapons systems. Recent papers by Middleton (1977b) and Doughty and Holder (1978) provide a thought provoking glimpse of the battlefield of the future. For example, consider the following hypothetical scenario:

"Project yourself forward in time ten years and assume that 25% more of Western Europe has been urbanized. Likewise, consider the throw-distance, accuracy and lethality of all weapons systems has increased 50%. The battleground will contain weapons platforms like the Black-hawk, dune buggy, trail bikes, XM1 and IFV. Therefore, mobility will have increased 20%. Hypothesize concommitant increases in all electronic acquisition, fire-control and fire and forget sensor systems."

Advances in long-range weaponry capabilities will expand the width and breadth of the combat zone and electronic reconnaissance devices will vastly increase the amount of information available for assessment of the enemy. In the development of graphic display requirements, it is essential to recognize the changing nature of the battlefield with respect to new doctrinal concepts and sophisticated weaponry, and to utilize and incorporate these advances.

Long-range weaponry, in particular, has complicated tactical assessment and planning by substantially augmenting the "reach" of modern attack units. Staging areas formerly used to marshall tanks for an attack are now fair game for precision weapons that strike out many kilometers forward of the line-of-contact with deadly effect. This suggests new imperatives for military planners, and by implication, for symbol users as well. Another major change in tactical thinking is that a conventional war with the Soviets would probably require NATO combined arms teams to fight outnumbered and outgunned. This imbalance would create a new requirement involving the ability to destroy specific enemy targets rather than to fire indiscriminately at the mass of targets that will surely appear. It means the situation map and its symbolic notations must be a "window on the battlefield" with sufficient resolution to match critical targets with appropriate firepower resources with a larger enemy, we can no longer afford the luxury of imprecision.

Additional technology-based tactical issues are emerging continuously which will impact directly upon the graphic portrayal of battlefield information. For example, there may be a shift away from the doctrine of large units (e.g., battalions, brigades) to small unit tactics. In this regard, Brigadier General Doyle (1978) has suggested that the XM1/IFV (infantry fighting vehicle) team *"will be the hub around which modern battle planning and operations will revolve."* Another issue emanates from commanders attitudes toward the attack helicopter. Though the attack helicopters are anti-tank weapons and maneuver units, they tend to be viewed as support units. Currently, maneuver units are generally regarded as ground units, and air units are viewed as support. To effectively utilize attack helicopters as maneuver units, the commander could be assisted by the graphic portrayal of these units.

Whether the symbolic portrayal of XM1/IFV teams and/or attack helicopters is feasible or even desirable is an issue which requires further investigation. Finally, the expanded dimensions and increased precision of battle are joined by the new time dimensions of battle. The imperative of "seeing the battlefield" deeply enough and early enough to ascertain where and when the main effort may come has become the critical dimension in war. An appropriate tactical response strategy is rooted in our ability to sort out the macro-formations leading to the point of penetration. Simply said, the map/symbol system must provide a more timely and clear picture of the enemy in depth.

2.3.2 Information Selection. Aside from addressing issues that pertain to the kinds of tactical information that should be represented in an improved symbology, formal and detailed account should also be taken of procedures for information selection. The requirements for such procedures are examined here in the form of specialized user group requirements. This section also includes a discussion of the notion that, with advanced systems, data selection becomes a question of data organization.

Specialized User Requirements. There currently exists no agreement as to what information should be displayed in a tactical symbology which would serve different user groups at various echelons. There is a general concensus that commanders at various levels have different informational requirements (Middleton, 1977a). For instance, captains at company level need intelligence information covering at least 5 km beyond the Forward Edge of the Battle Area (FEBA). Colonels at Battalion and Brigade level need information covering 50 km beyond the FEBA. Finally, generals at Corps and Division level need information covering 150 km beyond the FEBA. Each echelon will therefore prefer a different scale of map; the higher the echelon, the smaller the scale preferred. Similarly, the level of detail required for symbology varies with echelon. Corps commanders are interested in representing divisions, regiments, and brigades. Battalion commanders have little need to represent units larger than brigades or smaller than platoons or companies. General guidelines such as these, however, do not solve the persistent problem of determining the critical information needed to plan and execute military operations. To this end, Colson, Freeman, Mathews, and Stettler (1974) have developed an informational taxonomy of visual displays to portray the different information needs of personnel within a given command. Additionally, more recent work which addresses differences in graphic requirements across command levels within the Tactical Operations System (TOS) is also available (Modisette, Michel, and Stevens, 1978).

Processing all the information attendant to tactical decision making is difficult at any level. To be sure, even at the battalion level, as many as a half a dozen separate acetate drops might be necessary to "build" a comprehensive picture of the battlefield and the operational events planned. Occasionally, the chore of sorting out the detail can be a problem. Nevertheless, the number of symbols arrayed within the area of operations for a battalion is relatively finite.

At division and corps level, problems of clutter, abstract functional symbols, and information overload have taken on serious proportions. The number of information sources available has more than doubled, and the total number of symbols to be interpreted may have increased tenfold. Thus, corps and division represent priority targets for improved symbology development. The sheer volume and complexity of information processed at this level, as well as its tactical urgency, impose a considerable burden on command staff personnel.

Several specialized symbology systems are currently being developed, such as the Army Terrain Information System (ARTINS) proposed by the Engineering Topographic Laboratories (ETL), Intelligence Preparation of the Battlefield (IPB) (Gaun, 1976) and Combat Power Symbology (CPS) (Colanto, 1977). The major difficulty with specialized systems, tailored to meet the needs of various user groups, is that communication among users and echelons would be strained in the absence of a common language of symbology. On the other hand, the development of a large and comprehensive multi-purpose symbology is not without its problems. Users would be expected to learn an enormous amount of information; and in trying to serve "most of the users most of the time," the symbology would necessarily have to give up some degree of detail. Some compromise, therefore, between the global and specialized positions must be achieved before new forms of symbology can be developed and implemented.

Tactical Situation Requirements. Aside from standard differences in user needs, a different level of detail of symbolized information is required in different tactical situations. For example, though unit designations may be necessary for some battlefield tasks, such as communication, it may be viewed as clutter in other tasks, such as situation assessment. Also, Coates and McCourt (1976) found that although intelligence on enemy disposition was rated as valuable in all conditions of war evaluated, the perceived value of logistics intelligence increased with increasing intensities of war, while the value of tactics and training was greater in low-intensity conditions. Thus, it is clear that what should be represented in a tactical battlefield display is dependent upon the situation demands,; and therefore, a new symbology should have the capability to portray tactical information at different levels of detail.

Another aspect of the tactical situation is the specific battlefield terrain and how it interacts with the tactical circumstances. Gaun (1976) and Maggart (1978) have emphasized the need to analyze the relative advantages and limitations of the terrain in comparing possible courses of action. Though important aspects of the terrain have typically been represented on a maplike display, this method raises the issue of the distinctiveness of symbols in relation to a multicoded background. Aside from the question of symbology-background compatibility, the portrayal of topographic features on a maplike background leaves this information relatively unanalyzed with respect to its effect on the current tactical situation. A supplemental approach is to (a) portray a unit's terrain mobility as part of the unit's symbol as suggested by Sidorsky (1977), and (b) specify the enemy's avenues of approach on an overlay with broad arrows, as is currently done.

For a given situation, how can essential tactical information be differentiated from that which is merely useful? Depending on symbology formats, the problem may be partially or even completely sidestepped. The advent of computer-based display systems raises the possibility that improved symbology may be dynamic rather than static in nature. Whereas static symbology requires a one-to-one mapping of symbol-to-concept, a dynamic system is more flexible because it would permit the content of a symbol to change in response to changing user requirements. This adaptive capability of a computer-based symbology could effectively simplify the identification of essential information. The problem, in this context, will no longer be one of data compression--

since computer-based display systems can store and process vast amounts of tactical information--but rather one of data organization and access.

There is a growing literature describing rapid advances in automated data-processing (ADP) systems that allow for powerful graphic capabilities that are both efficient and economic. For example, recent research has provided the capability to analyze sightings of enemy forces automatically (Cooper, Reed, Kroger, Van Gorden, Aldrich, Hayden, and Mayhew, 1975; Moses and Vande Hei, 1978). These analyses include (a) chronological unit tracking, which provides information regarding the direction and speed of enemy unit movement as well as past changes in location, and (b) warnings of significant clusters of enemy activity (i.e., tactical indicators). Such techniques will likely facilitate the development and implementation of sophisticated improvements in tactical symbology to simplify the problems of information selection. A brief discussion of some general ADP-related issues is presented in Appendix A. However, the feasibility of implementing viable ADP systems to support graphic portrayal may well depend on whether the graphic codes used to express different kinds of information and levels of detail pose a perceptual problem for the symbol user. A detailed analysis of the behavioral issues in symbol design and utilization is presented in Chapter 4.

2.3.3 Symbology Implementation Issues

This section describes two basic restrictions on the manner in which tactical information should be represented: inter-service and inter-nation standardization, and user acceptance.

Symbology Standardization. Symbology development must satisfy a number of information exchange factors. First, even though there is little overlap in information requirements among services in the United States, an inter-service symbology would probably enhance communication (Middleton, 1977a). Currently, there is some liaison work between the Army and Air Force in the development in weather information requirements. Second, a tactical symbology must be standardized among NATO countries and their allies. Any new NATO symbology will have to be approved by NATO Panel XIII (NATO Document, AC/225, 1977), and such standardization is a lengthy process. Changes from STANAG 2019, which was introduced in 1962, have been kept to a minimum. Thus, it would be useful to consider the liklihood that a new symbology would be accepted by NATO. However, there is no formal organization to insure symbology standardization among non-NATO allies.

User Acceptance. In the development of a new tactical symbology, potential resistance to extensive change, especially among users who have invested considerable time and effort in mastering the FM 21-30 system, should be considered. This resistance points to the need to draw upon the strengths of the old system, when possible, and to augment these components with improvements to meet new requirements and considerations. With this approach, the user would not be asked to totally unlearn his previous training, and acceptance would be more likely.

Fortunately, it appears that most of the improvements must be developed for use by staff agencies during their assessment and planning phases. So, perhaps the changes in symbology that do occur will only impact on staff officers and probably only at headquarters levels where electronic displays will also be available. The doctrinal symbology now used to communicate and direct tactical actions can and should continue to serve that function. Assessment and planning at division and corps, on the other hand, might be facilitated by a specialized symbology designed especially for command staff personnel. In this way, the large majority of the tactical symbol users need not experience any future shock.

Many tacticians have expressed concern that high resolution and detailed electronic symbols won't work because we can't expect soldiers to duplicate these communications with a grease pencil on a map. While this is in fact a legitimate basis of concern, the graphic language used by upper echelon staff technicians need not necessarily be imposed upon subordinates who must execute tactical operations. Conventional symbology can be retained for purposes of tactical communication and coordination, while new symbology could, at least initially, be used exclusively by upper echelon personnel concerned with tactical planning and assessment.

2.4 Summary

The preceding analysis of selected issues regarding tactical symbology apears to have converged on a number of broad generalizations. These are listed below in summary form:

(1) Conventional symbology (FM 21-30) is able to portray only a fraction of the tactical information considered valuable by TOC personnel, and it does not accomodate most of the new "imperatives" of tactical doctrine (e.g., FM 100-5).

(2) Improved tactical symbology should be directed to serve a diversity of purpose and communicate a richness of detail (e.g., combined-arms composition, unit capability, information dependability) that is far beyond the scope of any contemporary system.

(3) Improved tactical symbology should offer the user a flexible system capable of adapting to different levels

of information selection (i.e., detail) to meet different user requirements and changing task requirements.

(4) Implementation of an improved symbology will necessarily occur within the limits of user acceptance and interservice and international standardization.

3. A QUERY-BASED METHODOLOGY FOR CONTENT ANALYSIS

3.1 Overview

This chapter will describe a methodology for eliciting and analyzing an expanded tactical database which could contribute toward the development of improved tactical symbology. The objective is to generate a broad sample of "concepts" that might be expressed in graphic form to facilitate the performance of complex and/or time-consuming tactical tasks. In order to insure a working relationship between the content and function of improved forms of tactical symbology, a concerted effort is required to establish a prospective set of task boundaries. We need, therefore, to decide what "questions" we want symbology to "answer." Once we have elicited a set of candidate questions from the military community, a second-stage elicitation can be conducted focusing more directly on task-based information requirements. This two-stage elicitation process represents a basic formula for the methodology that will be elaborated on in subsequent sections.

Our view is that content analysis should focus, at least initially, on eliciting meaningful tactical questions rather than declarations of support for one or more information categories. The goal, in other words, is to establish the functional breadth of tactical symbology in explicit task-based language. This objective will be made somewhat more manageable in the present analysis by focusing strictly on division- and corps-level command and control tasks. Even with this restriction, however, there remains a diversity of potential applications for new symbology. In order to delimit these task boundaries still further, therefore, a general framework for information processing was conceptualized for the upper-echelon Tactical Operating Center (TOC). This scheme attempts to identify the major parameters of task activity in the TOC and make it possible for the elicitation procedure to focus on one set of tactical circumstances at a time. After selecting a particular set of task parameters, the next step is to structure the elicitation procedure using both situational and doctrinally-sanctioned information prompts. The objective here is to stimulate the generation of candidate questions by focusing attention on the fundamentals of tactical decision-making (e.g., "Understand the Enemy"). Finally, the questions resulting from this elicitation process must be organized into thematically-related clusters.

3.2 Task Framework. The apparent concensus among military observers is that information processing at both corps and division has been severely strained in recent years due to the increasing availability of tactically relevant battlefield information. This suggests that improved military symbology will probably have its largest impact on high-level assessment and planning within upper-echelon tactical operating centers (TOC's). The objective of the current effort, therefore, is to develop a methodology for sampling the critical "questions" facing personnel within this highly pressured tactical context.

Our starting point was a simple task analysis, designed to identify those variables which regulate graphically-related information processing in the TOC environment. The following three components seem to capture the major dimensions of task activity:

(1) User Group - the military identity of the symbol user (e.g., Command Group).
(2) Military Operation - the tactical objective (e.g., Defense).
(3) Battlefield Terrain - the principal geography of the battle area (e.g., Rural).

A large number of subcategories can be identified within each of these major dimensions to define a wide range of tactical activity. The following sections describe these subcategories in some detail.

User Group. Three broad categories of symbol users can be identified within the TOC:

(1) Command Group - personnel who plan, supervise, and coordinate military operations including: Commander; Intelligence Staff (G2); Operations Staff (G3).

(2) Combat Support Staff - coordinators of field and/or air support operations including: Tactical Air Support Element; Airspace Control Element; Fire Support Element; Electronic Warfare Element; and Combat Engineer Element.

(3) Service Support Staff - coordinators of logistical and/or maintenance operations including: Personnel Officer (G1); Logistics Officer (G4); and Military Civilian Operations Officer (G5).

Military Operation. The tactical objective represents the first major task dimension. Four types of military operation can be distinguished:

(1) Offense - range of offensive scenarios includes: movement to contact; hostile attack; deliberate attack; exploitation; and pursuit.

(2) Defense - includes the defensive operations of: defend in place and delay.

(3) Retrograde - includes: delay; withdrawal; and retirement.

(4) Special Operations - includes a number of highly specialized operations, including: nuclear, biological, and chemical (NBC); psychological warfare; river crossing; airlift; airmobile; ranger; and night operations.

Battlefield Terrain. Four major categories of battlefield terrain can be identified:

(1) Rural - Characterized by hills, varying types of vegetation, rivers, streams, and lakes (e.g., Fulda Gap region of West Germany).

(2) Urban - Central cities as well as suburban areas characterized by extensive road networks and buildings.

(3) Desert - Chiefly characterized by sand dunes and sparse vegetation (e.g., Middle East).

(4) Mountainous - Sparsely vegetated, extremely rugged land characterized by high steep regions (e.g., Korea).

The identity of the symbol user, the tactical objective, and the geographical environment all combine to determine relevant information requirements. Each of these task variables can be integrated within a multi-dimensional framework to guide the process of task generation and analysis. One such framework is offered by the gross model illustrated in Figure 3-1. This model serves to organize major task parameters within a single unified system; these parameters establish the boundary conditions within which representative symbol-use tasks can be systematically sampled. The inner-most cluster of task components collectively define an "active" set of tactical task parameters. For example, the active parameters illustrated in Figure 3-1 specify Command Group as the user group, Defense as the military opration, and Rural as the battlefield terrain. These task variables can be systematically permuted to generate a large number of different tactical environments.

3.3 Elicitation of Content Requirements

The next step is to structure the actual elicitation process by providing analysts with set-inducing prompts to help stimulate the generation of

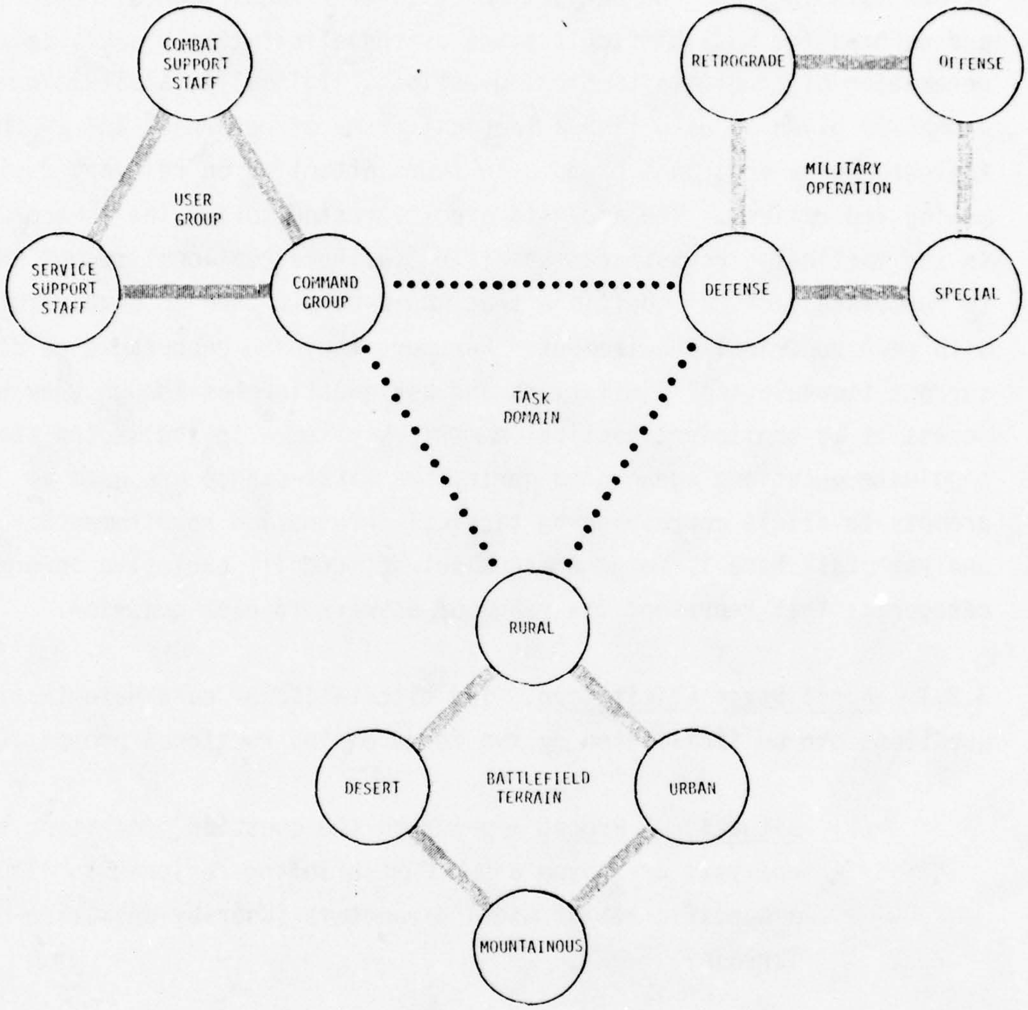


FIGURE 3-1. PARAMETERS OF INFORMATION PROCESSING IN THE TOC

candidate requirements. As mentioned previously, a two-stage elicitation procedure will help insure a linkage between the potential applications of new symbology and the derivation of content requirements. The first and perhaps the most difficult stage of the elicitation process is the generation of candidate tactical questions. Initially, a situational prompt is given to establish a tactical frame of reference and is then followed-up by doctrinal prompts to focus attention on relevant decision-making imperatives. The analysts are instructed to imagine themselves in the tactical circumstances specified by the situational prompt and to formulate tactical questions that would permit them to comply fully with each doctrinal requirement. Further, they are encouraged to disregard current technological limitations and ask questions as though they had access to an omniscient tactical computer system. In the second stage, candidate questions (generated during the first-stage) are used as prompts to elicit corresponding tactical information requirements. The analyst's task here is to generate a set of mutually exclusive information categories that represent the range of answers to each question.

3.3.1 First Stage Elicitation. The elicitation of candidate tactical questions can be facilitated by two forms of instructional prompt:

(1) Situational Prompt - prior to the question generation task, analysts are given a detailed briefing designed to illustrate a specific set of model parameters (User-by-Operation-by-Terrain).

(2) Doctrinal Prompt - fundamental tenets of tactical doctrine are presented one-at-a-time to focus the analyst's attention on critical dimensions of battle.

The initial selection of tactical task parameters (User, Operation, and Terrain) serves to define the basic elements of a situational prompt.

Each parameter is incorporated within a concrete tactical scenario designed to set the stage for the question elicitation task that is to follow. At a minimum, each scenario contains the following basic ingredients:

(1) A mission statement describing the general tactical objectives (offense, defense, etc.).
(2) An account of the events leading up to the present tactical situation.
(3) A topographic map background of an appropriate type (mountains, desert, etc.) and scale.
(4) A situation overlay at the division or corps-level which identifies an area of responsibility and illustrates a typical alignment of enemy and friendly units.

The description of a relatively specific tactical setting serves to impose broad restrictions on the analyst's question-generation strategy and hopefully will facilitate elicitation by focusing attention on a concrete set of "facts."

In summary, after receiving the scenario briefing, analysts are instructed concerning the proper response format for the generation task. Specifically, they are told to phrase all requests for information as tactical questions (e.g., Where are the enemy's command and control centers?) since this is the only form of input acceptable to the "computer." In order to stimulate the generation process, the analysts are also instructed to formulate their questions in response to particular doctrinal prompts. Each prompt is in the form of a statement describing doctrinally-sanctioned decision-making "fundamentals" and is derived directly from either FM 100-5 (Operations) or FM 71-100 (Armored and Mechanized Division Operations).

As an example, Chapter 5 of FM 71-100 presents a fairly detailed account of certain fundamental principles that are said to govern the conduct of defensive operations. The first decision principle is to "Understand the Enemy". Specifically, the manual states:

> *"Commanders must be thoroughly familiar with the capabilities and limitations of enemy weapons and equipment. They must know how enemy units are organized, how the enemy organizes for combat and deploys, and how the enemy fights - in other words, the echelonment and tactics of enemy units..."*
>
> *"...the division commander and his staff must also have a sound understanding of where enemy field and air defense artillery, combat service support, and critical command control facilities can be found. These are the systems the division must destroy so battalion task forces, attack helicopter units, and USAF air support can operate successfully against enemy tactical formations."*

The preceding quote serves to illustrate a doctrinal prompt that can be used to remind the analysts of a basic principle underlying defensive operations. A series of such prompts can be derived for each of the major types of tactical operations and used to structure the elicitation of tactical questions.

In the case of defense, for example, doctrinal prompts can be used to specify (in some detail) the following information processing requirements (FM 71-100):

(1) Understand the Enemy

(2) See the Battlefield

(3) Concentrate at the Critical Times and Places

(4) Fight as a Combined Arms Team

(5) Exploit the Advantages of the Defender

Each prompt represents a detailed account of current decision-making requirements and can be presented one-at-a-time to stimulate the question generation process. Elicitation instructions can encourage analysts to generate all the tactical questions they can think of to comply in full with each requirement. The only restriction on the generation task will be imposed by the situational framework in which the analyst is assumed to be operating.

3.3.2 Second-Stage Elicitation. The output of the initial elicitation process is a set of candidate tactical questions corresponding to a sequence of doctrinal prompts. The issue then for the second-stage elicitation process becomes the translation of these candidate questions into corresponding information requirements. The procedure for accomplishing this is to present analysts with their own (previously generated) questions in an effort to elicit candidate answers. Each response should, theoretically, represent a set of mutually exclusive and exhaustive information categories corresponding to the range of possible answers. For example, an analyst may have asked the following tactical question during initial elicitation: "What is our present mobility status?" As it stands, the question is ambiguous since the information required to answer it can range from a relatively specific qualitative concept (e.g., AH6 or attack helicopter) to a relatively summarized estimate of overall mobility (e.g., 50%). The second-stage elicitation process has therefore been designed to clarify these ambiguitities and simultaneously define a set of candidate information requirements.

After prompting the analysts with a question and receiving a candidate set of "answers", the intermediator first attempts to verify that the proposed information categories are in fact mutually exclusive and that they exhaust the set of possible answers. These two criteria - exclusivity and exhaustiveness - represent minimum standards for accepting a category set as a valid response. For example, in response to the mobility question an analyst may generate the following set of candidate categories: Wheels; Tracks; Rail; Air; AH6. The intermediator would then ask whether the "Air" and "AH6" categories overlap or are, in fact, independent (i.e., "Air", in the mind of the responder, may refer to both fixed wing and rotary aircraft and therefore overlap with "AH6"). After defining each such response concept the intermediator goes on to ask whether any other categories can be thought of which also represent possible answers to the question. Each tactical question generated during stage-one can be filtered through both of these validation criteria in order to:

(1) clarify the level of information detail required for an acceptable response

(2) operationally define a candidate set of mutually exclusive and exhaustive response categories

The output of this second-stage elicitation is a set of candidate questions along with a corresponding set of candidate answers. The idea is that each candidate information category (e.g., AH6) could ultimately be considered in the assignment of unique graphic codes (i.e., symbols) in the development of new systems of tactical symbology.

Summary of Elicitation Technique. The elicitation technique can be applied in an iterative fashion to elicit candidate requirements over a wide range of task domains. A brief review of the sequence of steps required to implement the technique is as follows:

(1) Select and recruit a small group of military experts to serve as analysts.

(2) Administer first-stage elicitation instructions to the group (i.e., describe the question-generation task).
(3) Administer second-stage elicitation instructions (i.e., describe answer-generation task).
(4) Start by selecting one set of task parameters (using the model in Figure 3-1) and then systematically vary other parameters.
(5) Present situational prompt based on selected parameters (i.e., induce an appropriate tactical frame of reference).
(6) Present first doctrinal prompt (taken from FM 71-100).
(7) Elicit candidate questions (first stage).
(8) Elicit candidate answers (second stage).
(9) Review each set of questions and answers (modify, add, delete, as necessary).
(10) Add new acceptable questions to existing question set.
(11) Present next doctrinal prompt.
(12) Repeat Step 7 through 11 until all prompts have been presented.
(13) Return to Step 4, or exit if all desired task parameter combinations have been exhausted.

Finally, the advantages of this elicitation technique can be summarized in terms of its breadth; namely, that it accounts for variations in user functions, operational objectives, and situational variables including battlefield terrain.

3.3.3 Organization of Requirements. After completing the two-stage elicitation task, the analysts' questions can be sorted into thematically related clusters. For example, one doctrinal prompt may lead analysts to ask "Which are the combat units?", while later another prompt may elicit, "What type of combat units are they?". Each of these tactical questions is thematically related since each pertains to an analysis of unit function. At the most abstract level, one may simply wish to know whether combat or support-type units are being faced, while under a different set of circumstances one might wish to draw more precise functional distinctions (e.g., mechanized infantry vs. armor). At a still more detailed level, one may even want to know the cross-attachment structure or the special weapons that have been assigned. Each of these different levels of information detail could conceivably be appropriate depending on the tactical circumstances. Different users at different echelon levels, or with different objectives, might each require information at different levels of specificity. The result would then be a variety of questions on the same topic generated by different users under similar circumstances or by the same user at different times.

The problem at hand then becomes the organization of these subject-generated questions into thematically-related clusters. Each cluster could ideally contain a sequentially ordered set of questions corresponding to different levels of tactical analysis or, alternatively, to different levels of information summarization. For example, consider a sample sequence of tactical questions pertaining to "unit function".

Level 1: Which are the combat units?
Level 2: What type of combat units are they?
Level 3: What is their composition?
Level 4: What is their special weapon capability?

The questions in this particular example are ordered along an underlying dimension of summarization. As one moves down the list of questions, each one entails successively more detailed answers. Under certain circumstances, the symbol user might require an overview of the tactical situation, vis-a-vis unit function, and so limit himself to asking only one or two highly summarized questions. On the other hand, the user might wish to pursue the analysis down to the lowest possible level of detail. The ultimate objective of content analysis, therefore, could be the derivation of tactical data structures that offer the symbol user selective access to different levels of information detail.

Several methodologies, both informal and formal, may be employed to determine categories of thematically related questions and the perceived importance of the questions within categories. The informal techniques are based largely on the capability of the research investigators to rationally organize and structure questions. The more formal, empirical methods range from factor analysis to multidimensional scaling and hierarchical cluster analysis. Factor analysis requires the collection of importance ratings using scales of the attribute dimensions while scaling requires assessments of perceived similarity among questions; the simplest approach involves the derivation of measures of similarity or relatedness for the questions. This could be accomplished by having analysts sort questions into conceptually related sets. Whatever the case, an analysis could be designed to identify the basic conceptual dimensions of tactical information (by sorting questions into clusters), as well as the relative priority of information within each dimension (by rank-ordering questions within each cluster). The outcome would be a set of multi-leveled data structures that operationally define prospective content requirements for improved tactical symbology. For example, clusters entailing tactical vulnerability, capability, threat, mobility, etc. might result.

3.4 Application of Elicitation Methodology: A Preliminary Study

3.4.1 Introduction. The objective of this section is to explore the feasibility of applying a query-based approach to the elicitation of candidate information requirements for tactical symbology. An informal pilot study was conducted, using the military members of our research team as participants, and, as a result, a preliminary set of tactical data structures was defined. The scope of this initial inquiry was restricted to a single triad of tactical task parameters: Command Group-by-Defensive Operation-by-Rural Terrain. These parameters serve to prescribe an especially important tactical setting:

> *Division-level command personnel using symbology to assess the enemy situation and plan appropriate countermeasures in an active defense of Western Europe.*

The selection of these particular task variables was intentional, since they collectively represent the most challenging set of circumstances likely to confront the military decision-maker (cf. the "European" scenario as described by General Starry, 1978). They are also the circumstances most often assumed during battle simulations at the Command and General Staff College (CGSC) at Ft. Leavenworth (e.g., CATTS; BATTLE; etc.).

3.4.2 Methodology. The research plan for the present study was based on the two-stage elicitation process described in the previous section (3.3). The participants were initially instructed to generate candidate tactical questions in response to a set of situational and doctrinal prompts. The resulting questions were then used to facilitate the elicitation of corresponding information requirements.

Participants. Two Army officers, both with extensive experience as teachers and developers of tactical doctrine at CGSC, participated as analysts. One is an LTC with a background in Intelligence, while the other is a Major with a background in Operations. The former was an Instructional Designer at CGSC from 1972-1978 and was responsible for enhancing the tactical validity of various battle simulations (e.g., CATTS; White Knuckles; Battle; Indian River I, II, and III; and Goldfire I). The latter was responsible for aiding the development of the above battle simulations and evaluating the performance of student decision-makers in related simulation exercises.

First-Stage Elicitation. As previously defined, the task variables at issue in the present study were: Command group personnel conducting a defensive operation in rural terrain. A tactical scenario based on these parameters has been developed by CGSC faculty and is currently used in a semester-length course entitled "Forward Deployed Force Operations (European Setting)". The scenario specifies a set of strategic developments leading to an outbreak of hostilities between NATO and the Warsaw Pact nations. It also includes a description of enemy and friendly forces along the international border in the Fulda Gap region of Germany. Briefly, the 10th U.S. Corps, consisting of the 23rd Armored Division and the 52nd Mechanized Division, is assumed to be opposing elements of the First Zapadnian Front (a vastly superior enemy force). In the present context, this scenario was used as a situational prompt to help the analysts adopt the desired "mental set". Each analyst was given a small booklet containing a description of recent strategic events; an analysis of friendly and enemy forces; and a situation overlay (acetate) on a 1:250,000 scale map of the area (USACGSC 250-138). A copy of this scenario and the situation overlay are presented in Appendix B. Since both analysts used in the present study were already familiar with this material, time required for indoctrination was minimal.

The next step was to administer the following set of elicitation task instructions:

"It is now 0430 on 21 August 1979. As the G2 (G3) section TOC duty officer of the 23rd Armored Division, it is your responsibility to prepare situation summaries and formulate recommendations for future operations. The deployment of friendly and enemy forces shown on your situation display is now approximately 4 hours old. Recent developments may have altered the situation. The division commander has ordered you to:

(G2) Prepare an update briefing on current enemy threat.
(G3) Recommend friendly troop deployment against potential enemy threat.

In order to help you in this task, imagine that you will have access to a new computer system capable of answering any meaningful tactical question you can imagine. This computer is linked to a comprehensive intelligence-gathering system and can provide you with up-to-the-minute information about either the enemy situation; your own forces; or current terrain conditions. In short, you can ask for any type of information or overlay that you might find useful. The only restriction is that your inquiry must be stated in clear operational language. For example, you cannot ask "What is the enemy's combat effectiveness?" since the term "effectiveness" as used here is not clearly defined. If you ask a question calling for summarized information like an estimate of overall effectiveness, you must first define the concepts you think should be included. For example, it is permissible to ask "What is the current ratio of enemy to friendly firepower effectiveness in terms of weapon range and ammunition available?"

Remember you can ask for detailed information or any form of graphic overlay that might help you to assess the situation or plan for future operations. On the following pages, you will find a list of doctrinal requirements that may help you think of questions to ask. Please read each statement carefully and then write down all the questions you can think of that might help you to comply with each requirement."

One analyst, the intelligence officer, was given instructions relating to the G2 task, while the other analyst, the operations officer, was given similar instructions but relating to the G3 task (indicated above in parentheses). Each analyst was then given a response booklet containing a set of doctrinal prompts (one per page) relating to the fundamentals of defense. Each prompt represented a doctrinally-sanctioned guideline for information processing by command-level personnel. Table 3-1 lists each of these prompts in the order in which they were presented (each was excerpted directly from FM 71-100).

Second-Stage Elicitation. The second elicitation task was conducted ten days after completion of the first elicitation task. Each analyst was given a response booklet containing his own tactical questions (typed four to a page) and asked to generate a set of possible "answers". The instructions were as follows:

> *"Your objective on this task is to generate a set of "responses" corresponding to each of your tactical questions. In other words, try to identify the range of possible answers you would expect in response to each of the questions. For example, in order to answer "What is the enemy's principal areas of deficiency?", the following set of responses might be necessary: POL; Ammo; People; Mobility; Morale. These five concepts may or may not exhaust the set of possible answers, the point is that you should generate all the answers that are of interest to you. Perhaps you're only interested in two or three possible answers and if so just list these. Besides listing the range of answers for each question, try to make sure that the set of answers you select are all roughly at the same level of detail and that each is independent of the other. Consider the previous question once again: "What's the enemy's principal source of deficiency?" The set of answers here can range from a few rather summarized (or abstract) responses to a larger number of detailed responses. The following represent two possible sets of replies: (1) combat arms deficiency; combat support deficiency; service support deficiency; (2) POL; Ammo; People; Mobility; Morale. Either set of answers may be valid and/or useful depending on the level of detail you require to perform your task. For each question listed in the booklet, please generate one set of responses which you think represents the level of detail required to provide a useful and satisfactory answer to the question. If more than one set of responses seems necessary to you, then list each one separately."*

As in the previous elicitation task, each participant worked independently with no pre-established time limitation.

TABLE 3-1

DOCTRINAL PROMPTS FOR DEFENSE

1. UNDERSTAND THE ENEMY

Commanders must be thoroughly familiar with the capabilities and limitations of enemy weapons and equipment. They must know how enemy units are organized, how the enemy organizes for combat and deploys, and how the enemy fights--in other words, the echelonment and tactics of enemy units. ...As in offensive operations, the division commander and his staff must also have a sound understanding of where enemy field and air defense artillery, combat service support, and critical command control facilities can be found. These are the systems the division must destroy so battalion task forces, attack helicopter units, and USAF air support can operate successfully against enemy tactical formations.

2. SEE THE BATTLEFIELD

Prior to the battle, the defending commander must organize to defeat different types of likely attacks from several feasible directions. He must then undertake aggressive operations to learn where the enemy is, how he is organized, which way he is moving, and what his strength is. As the battle unfolds he must seek to establish a continuous flow of information, and must deny the enemy similar information about his own forces as he maneuvers to counter the enemy and seek an opportunity to attack.

Battalion task force and brigade commanders can seldom see beyond terrain features to their immediate front. A brigade commander needs information about second echelon regiments, while the division commander needs information about second echelon regiments and divisions. To get such information the division commander will turn to his own collection means. Despite his best efforts though, the division commander will almost always have to make decisions based on incomplete data. Therefore, the more he knows about enemy weapons and supporting systems, tactics, psychology, and the terrain, the better his decision will be.

3. CONCENTRATE AT THE CRITICAL TIMES AND PLACES

The commander must decide exactly when and where he will concentrate his forces; hopefully, he does this based on the satisfactory results of his combat information and intelligence-gathering operations. He must also decide how much force will be required to defeat the enemy within the terrain and space limitations of the defensive area.

To defend against enemy breakthrough tactics, the commander must not only concentrate forces at the right time and place, but he must also take risks on the flanks.

...It may be necessary to concentrate up to six or eight maneuver battalions on one-fifth of the division's front to meet breakthrough forces which may number 20 to 25 battalions. Remaining ground is then covered with air and ground cavalry, remaining battalions, and attack helicopter units.

...The division commander must aggressively use the high mobility of his armored and mechanized forces to build up forces rapidly, using units from adjacent areas and from less threatened flanks. With ground units he must make the decision to concentrate fairly early, but not too early. If he makes a mistake and starts to concentrate at the wrong place, he may countermarch his mobile elements many times trying to rectify the error. The high mobility of attack helicopters permits the commander to move them quickly, concentrating first at one point, then another, without disruptive "counter-marching." This fact makes attack helicopter units ideal outfits to go find the enemy early, signal his approach, and fight him--disrupting his attack while the rest of the force concentrates.

Concentration of field artillery is equally important. Field artillery fire can often be concentrated without moving batteries. In extended areas, however, field artillery batteries must be moved to positions within range of the main battle.

Air defense batteries and platoons pose a special problem. The first priority for deployment of division air defense batteries in the defense should be protection of the division command control facilities and operations in the division support area. Some Vulcans may be used to protect forward brigades.

...Close air support must be applied in mass, in time, and at the critical point, supported by a well planned and conducted air defense suppression operation.

4. FIGHT AS A COMBINED ARMS TEAM

As friendly units converge on the critical battle site, commanders commit them to combat according to their weapons' capabilities and movement of the enemy force.

The first increment of combat power available is usually the massed fire of all field artillery in range. Even if artillery fire does not destroy large numbers of armored vehicles, it causes tank crews to button up, reducing their effectiveness. Field artillery can effectively discourage enemy infantry from dismounting to attack defending dug-in antitank weapons. Field artillery can also smoke overwatching forces covering the enemy attack.

The second increment of combat power available could be attack helicopters. Reinforcing at speeds of 125 knots, attack helicopters have a high probability of killing enemy tanks at ranges beyond 3000 meters. Attack helicopters will be most useful when the enemy has moved out from under, at least part of, his air defense umbrella and beyond his preplanned artillery fires.

...As the battle develops, the commander must move defending forces from one position to another to take maximum advantage of his weapons, the terrain, and mines or obstacles that he has been able to employ. Combat vehicles must be refueled, rearmed, and repaired as far forward as possible and quickly returned to battle.

5. EXPLOIT ADVANTAGES OF THE DEFENDER

The defender's advantages are numberous and permit a numerically inferior force to defeat a much larger attacker. Perhaps the defender's greatest advantage is the opportunity to become intimately familiar with the terrain prior to the battle. The attacker cannot do this. The defender can prepare the ground in advance, building obstacles, firing positions, and improving routes between battle positions. The attacker can only guess at these. The defender can fight from cover while the attacker is in the open. The defender can shoot first and force the attacker to react. The defender can shoot from stationary platforms or positions while an attacker must move. The defender can shift forces from prepared position to prepared position swiftly to concentrate for successive engagements. The attacker must feel his way over the terrain, seeing each new compartment for the first time. The defender can plan communications, control measures, fires, and logistical support in advance to *fit many predictable situations. The attacker must adhere to a predetermined course of action and risk being out-maneuvered, or must alter his plans as the battle develops and suffer from uncoordinated effort.*

Each position should combine the best characteristics of a defense and an ambush. Several positions designed for mutual support should be used to multiply the strength and value of each. The combination of all these advantages repeated in each set of positions in depth, supported by field artillery, offensive air support, and attack helicopters, should enable the defender to inflict very high losses on an attacking enemy.

3.4.3 Analysis. Both analysts were able to generate a substantial number of candidate questions during the first-stage elicitation procedure (a complete list of responses for each subject is provided in Appendix C). The first step in reducing these data was to identify and eliminate those questions that seemed to be redundant. This was accomplished first on a within-analyst basis and then on a between-analyst basis. The procedure was to informally compare the similarity of the answers given to each question and eliminate those which seemed to overlap. After eliminating redundant questions both within and across analysts, each of the 72 remaining candidate questions was then typed on a separate index card. Both participants were then each given a complete deck of questions and instructed to sort them into meaningful clusters or "chunks" of tactical information. No restrictions were placed on the number of clusters that could be used or on the selection of an organizational strategy. After the sorting task was completed, subjects were instructed to generate a "label" for each cluster to identify the theme or underlying dimension on which the sorting judgment was based.

The results of the sorting task revealed some disagreement among the participants as to the number of tactical clusters necessary to organize the candidate questions. The "G2" subject generated 19 different clusters, while the "G3" generated 15. The contents of each cluster as well as the perceived "theme" also varied from one analyst to the other. However, 12 clusters were roughly synonomous in theme, yet of these, only 3 contained identical tactical questions.

Since the number of participants (only two) did not permit a formal statistical approach to resolving differences of opinion, an effort was made to achieve an informal concensus on each cluster through group discussion with an intermediator. With this objective in mind, the sorting task was performed a second time in a group setting. The sorting rule was that both experts had to agree before a candidate question could be assigned to any tactical cluster. After the group sorting was completed, a group labelling procedure was undertaken to clearly specify the tactical theme of each cluster (both participants had to agree before a particular label was "accepted").

Next, the individual questions within each cluster were rank-ordered (again in a group setting) to produce a sequence of successively more detailed tactical questions. The objective was to construct a hierarchy of tactical analysis for each cluster (i.e., a tactical data structure). Instructions specified that questions calling for summarized information should be ranked higher than related questions calling for more detail. A number of clusters, however, were relatively homogeneous with respect to the level of detail variable. The instructions, therefore, also emphasized that ranking should reflect the temporal sequence in which the questions should be asked. In other words, the objective was to construct a coherent sequence of questions within each cluster corresponding to an orderly analysis of tactical information.

Our approach can be contrasted to rank ordering on the basis of perceived tactical "importance." We reasoned that an "importance" ranking is necessarily context-bound and will probably fail to generalize over different situations. For example, depending on the circumstances, a user may or may not have sufficient time to pursue a particular line of analysis down to the lowest level of detail. If future symbology is to offer the user a tactical database that he can adapt to meet his changing needs, then access to questions within the database should probably not be "fixed" to reflect static information priorities. Rather, questions might better be arranged along a "levels of analysis" dimension to offer more flexibility across a wide range of tasks and situations.

3.4.4 Results. A total of 22 candidate clusters, each centered on a different tactical theme, resulted from the group sorting task. A description of these clusters appears in Exhibit 3-1 (presented at the end of this chapter), with one cluster shown on each page of the exhibit. The presentation format for a cluster begins with a heading which labels the theme or concept represented, followed by a key tactical question addressed by the cluster. Next, a brief rationale for supporting the tactical need and relevance for the question cluster is provided. Finally, an ordered set of constituent questions and answers (i.e., the data structure) is portrayed. In certain cases, it should be noted, conventional tactical questions considered by the participants (e.g., what type of enemy units oppose me?...what size are they? - see Table 2-1) were not included in the data structures since their information requirements are already well known.

Each cluster presented in the exhibit represents a set of candidate questions pertaining to a common tactical theme. The objective of the present methodology, as described previously, is to operationally define each cluster in terms of an ordered list of tactical questions-and-answers, that is, in terms of a tactical data structure. The data structure concept, as illustrated by each page of the exhibit, represents the basic building-block of a tactical database. It explicitly identifies a set of tactical tasks that a new symbology might accommodate (in the form of questions) and, in so doing, defines a corresponding set of candidate information requirements (in the form of answers). The depth of each structure, that is, the number of questions it contains, reflects the depth of tactical analysis which it addresses. The breadth of each structure, on the other hand, reflects the range of responses it can provide. Each one, in effect, represents a model of information that could, if expressed graphically, provide an easy-to-understand format for tactical assessment and planning.

3.4.5 Implications. The use of automated systems to process, store, and display battlefield information may effectively expand the role of military symbology in combat operations. A basic requirement of such automation, however, is that tactical information be organized into meaningful and readily accessible structures or "chunks". The preceding set of query-based data structures represent one way in which tactical information can be chunked and stored for rapid retrieval. Each structure is task-oriented and can be selectively accessed to retrieve information at different levels of tactical detail. For example, consider the analysis of "Type of Threat" (Item 2 in the exhibit). Under certain circumstances, the user may only have time for a quick overview of the situation - all combat-type vs. all support-type units. In another context, he may wish to conduct a more elaborate analysis by selecting finer levels of information detail (e.g., by asking for "unit composition" or "special weapons"). In effect, each data structure represents a potential building-block in the development of a dynamic database for tactical symbology.

The preceding discussion suggests that data organization will play a fundamental role in determining the effectiveness of new symbology. Ideally, the database should be compatible with the military user's own mental organization of tactical knowledge. Specifically, in order to address the database, a user must first understand: (a) the relationship between the specific tactical task requirements and the available corresponding database structures, and (b) the inherent organization of data within each structure. In other words, the user must be able to translate his/her current task objectives into a corresponding set of tactical questions.

Each question offers the user an opportunity to bridge the gap between task demands and the location or "address" of required information. In practical terms, the first step for the user is to identify the tactical theme to be pursued (e.g., Type of Threat) and then the level of detail at which the user wishes to operate. These two decisions define the database coordinates at which the user enters the system. Ultimately, the dynamic symbology corresponding to the activated data structure may then provide the user with a graphic read-out of the requested information.

Finally, it should be emphasized that the data structures presented in the exhibit are intended to be illustrative since they are based on elicitation data from only two military analysts. It is quite conceivable that other analysts would have generated different questions, answers, and patterns of data organization. Eventually, however, it will be essential for all useful data structures to reflect the best judgment of the Army's tactical community at large.

3.4.6 Summary. Given the far-reaching potential of improved symbology for graphically communicating tactical information, a task-oriented doctrinally-based elicitation procedure was developed to obtain diverse, representative information requirements that might ultimately be served by modern tactical symbology. These requirements were determined in the form of candidate questions and answers which would likely emerge in a goal-directed, typical TOC-level tactical assessment and planning exercise. To test the practicality of the query-based procedures, data were elicited from two experienced tacticians in the context of a defensive, tactical scenario. These data (questions and answers) were then systematically organized into clusters of thematically related, ordered information (i.e., tactical data structures).

The problem of selecting essential information requirements may eventually be dominated, in the case of computer-based symbology, by the problem of organizing data into meaningful "chunks." In this regard, tactical data structures (i.e., clusters of related tactical questions) appear to provide a useful tool for representing the information content of improved symbology. These structures can be defined in terms of their depth--the level of detail at which concepts are specified, as well as their breadth--the range of concepts they address at each level. The data structures are task oriented and are designed to permit selective retrieval of information at different levels of tactical detail.

EXHIBIT 3-1

CANDIDATE CLUSTERS OF TACTICAL QUESTIONS

1. IMMEDIATE THREAT

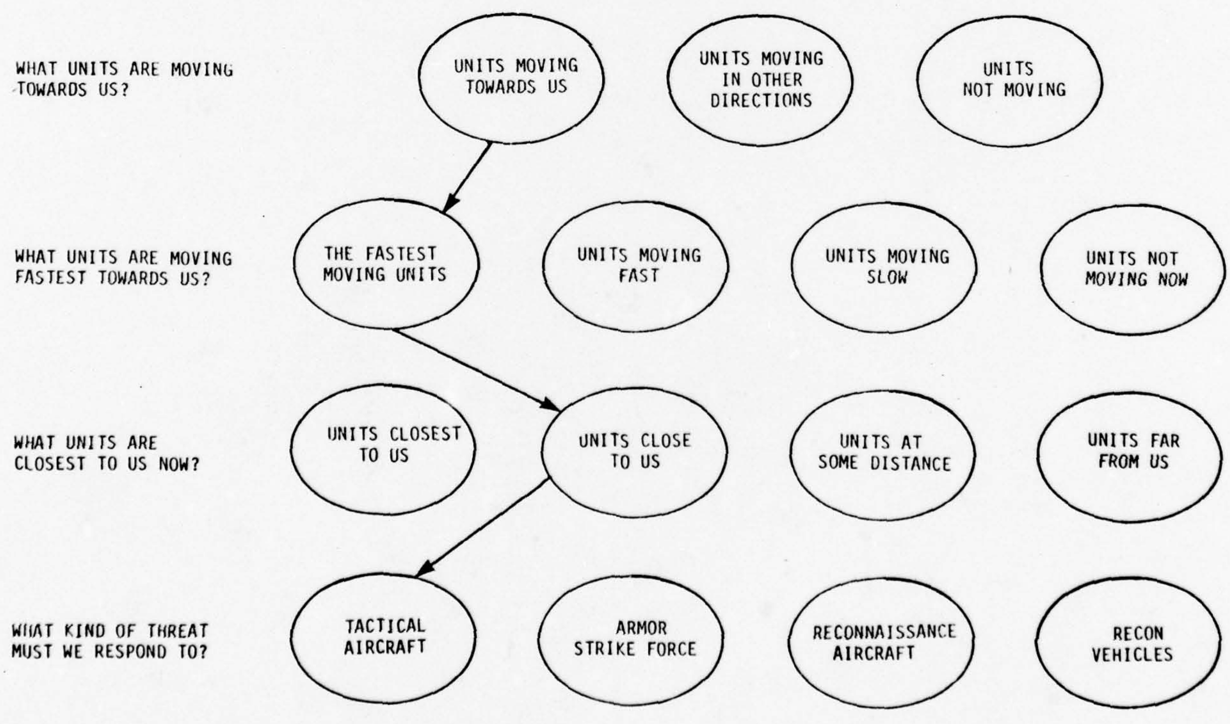
Key Question:

"Which enemy units are closing in the fastest?"

Rationale:

Very seldom does the resolution of reports about enemy activity manifest itself on the battlefield display system. As the staff goes busily about planning, communicating, and reacting to radio requests, the focus of response often centers on the movement of friendly units rather than actions taken to destroy enemy units. If at anytime a commander glanced at the situation display and could see which enemy units were currently moving toward him, and, further which ones should be dealt with first, then his priorities would be more clear. If the enemy is doing something dynamic then that action should be communicated dynamically on the display. Static reports and displays cannot keep pace with modern battle.

Data Structure:



2. TYPE OF THREAT (UNIT FUNCTION)

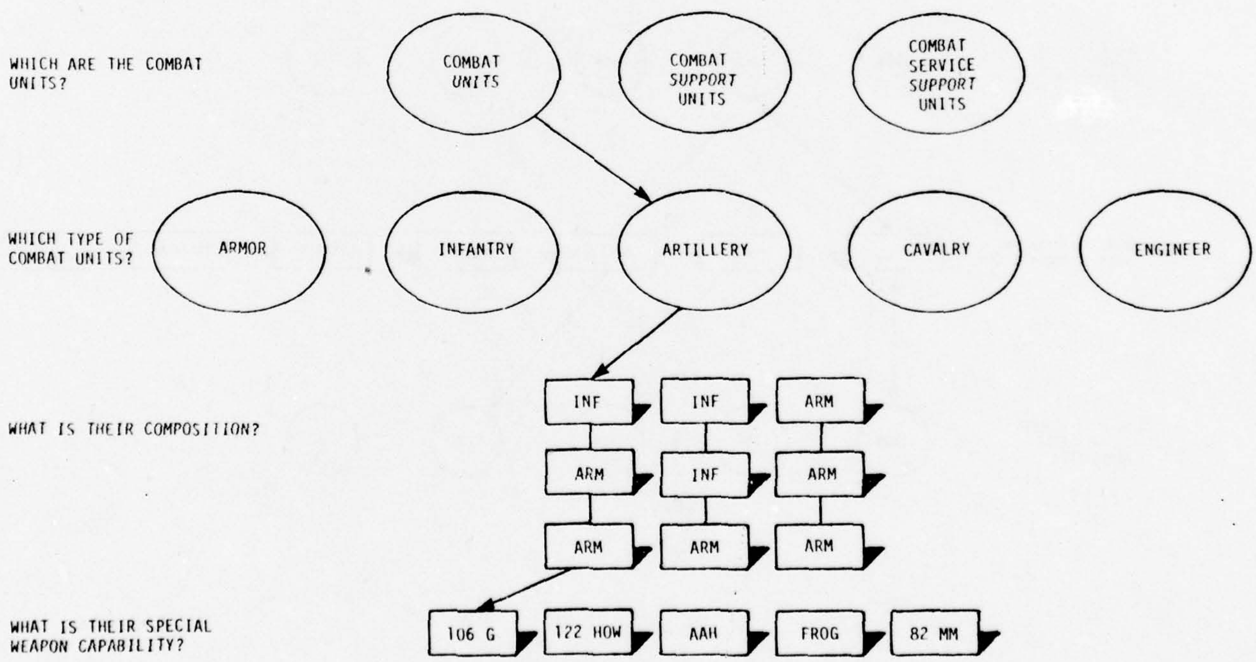
Key Question:

"Where are the preponderence of the enemy's combined arms strike forces?"

Rationale:

"What are we up against?" So often, using the current map-display symbol system, it is near impossible to sort out those enemy units that have "teeth" and those who don't. Further, it is useful for the intelligent selection of firepower resources to know exactly what kind of weapon systems you face. This kind of display would permit precision counter-punching as well as the efficient use of resources in an anticipated conflict where we are to be outnumbered and outgunned.

Data Structure:



3. POTENTIAL OF THREAT (UNIT CAPABILITY)

Key Question:

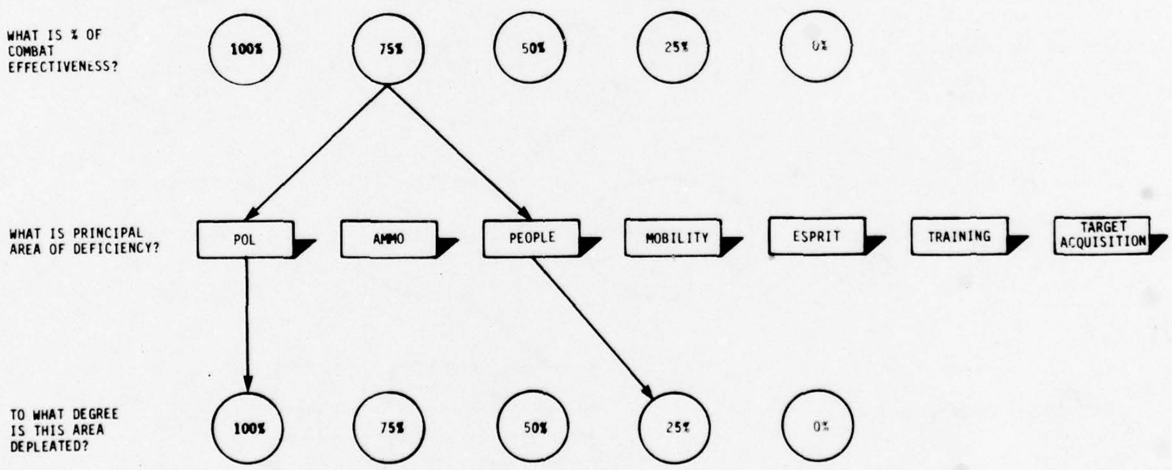
"Just how strong are the enemy units?"

Rationale:

If we're faced with an armored regiment bearing down on us then it makes a great deal of difference to us to know if he's lame, or low on gas or at only 50% strength. The Order of Battle unit designator may be "regiment" but if it only has the punch of a "battalion" then that status is critical information, and it should be accurately displayed for each of the enemy's dimensions of potential.

Data Structure:

3. POTENTIAL OF THREAT (UNIT CAPABILITY)



4. PRIORITY TARGETS

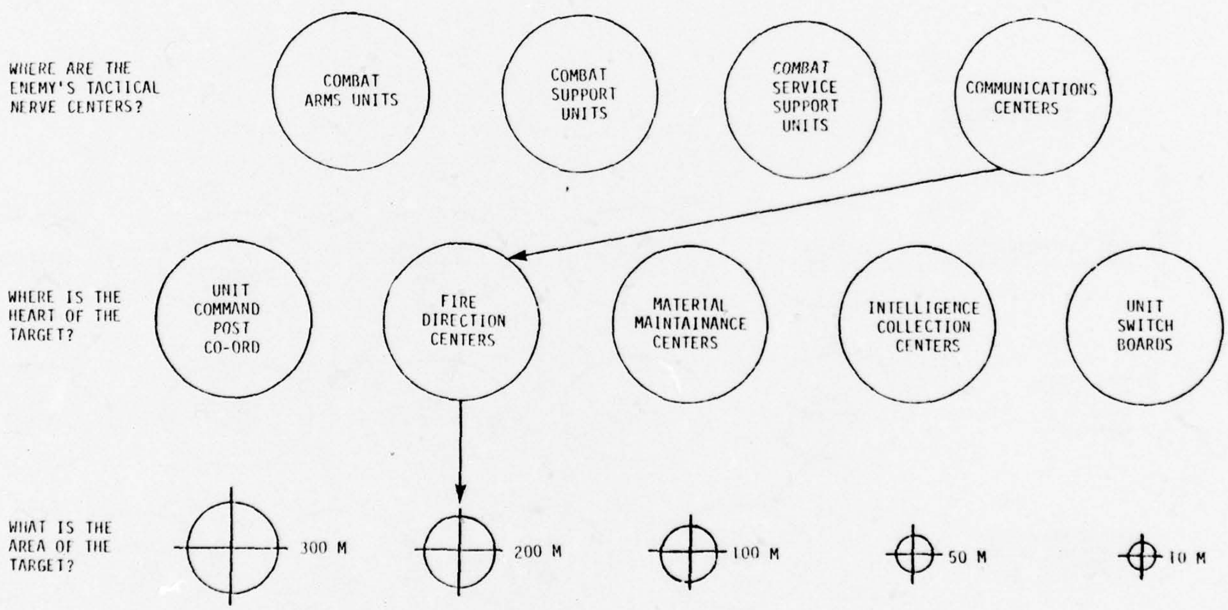
Key Question:

"Where are the critical enemy targets such as the command posts, fire direction centers and communication centers?"

Rationale:

There is a need for priority targets to be seen as standing out from the maze of enemy units. Using the current map symbol system, it is extremely difficult to pick out those enemy targets where fire should be concentrated.

Data Structure:



5. ENEMY VULNERABILITY

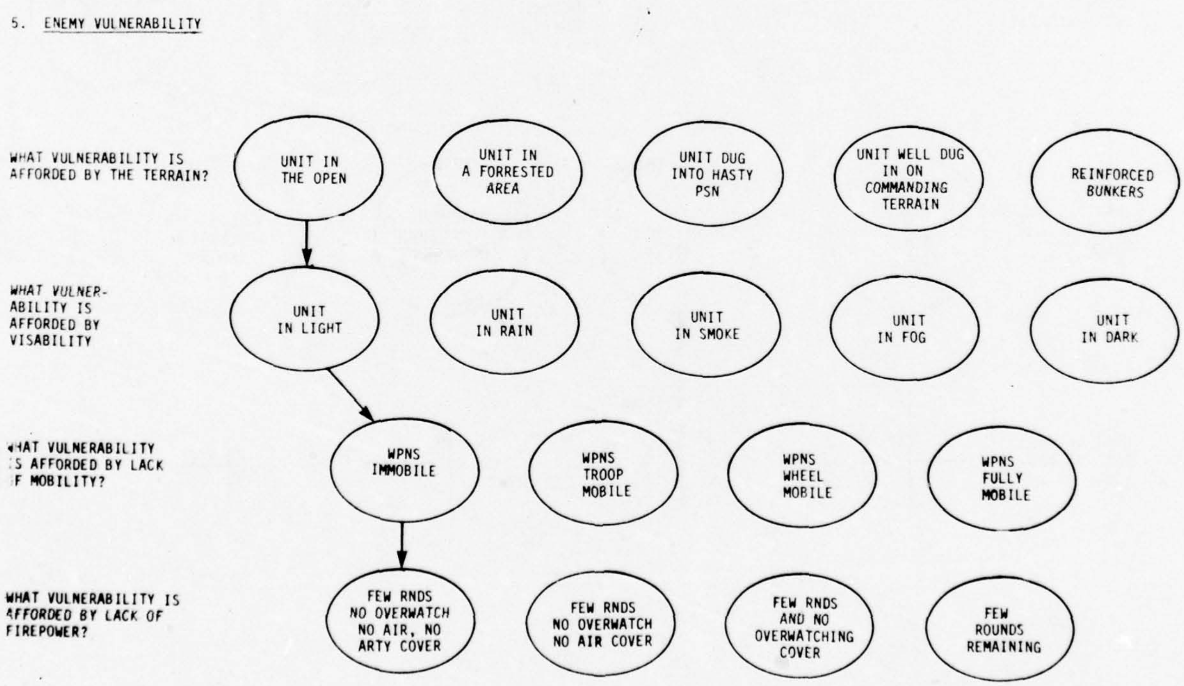
Key Question:

"What is the nature of the enemy's weakness?"

Rationale:

What makes an enemy force a vulnerable target? When deciding which enemy force to commit the bulk of our assets against, it makes a real difference at a tactical level to know the unit's current situational status. Is he operating on defensible terrain? Is he obscured by smoke? Is he immobilized by an obstacle and in the open? What about his back up firepower? These conditions surrounding his ability to protect himself will often be too temporary to recode on a display, but since that is not always the case some provision should be made within the symbol language to accomodate same.

Data Structure:



6. REACH OF THREAT

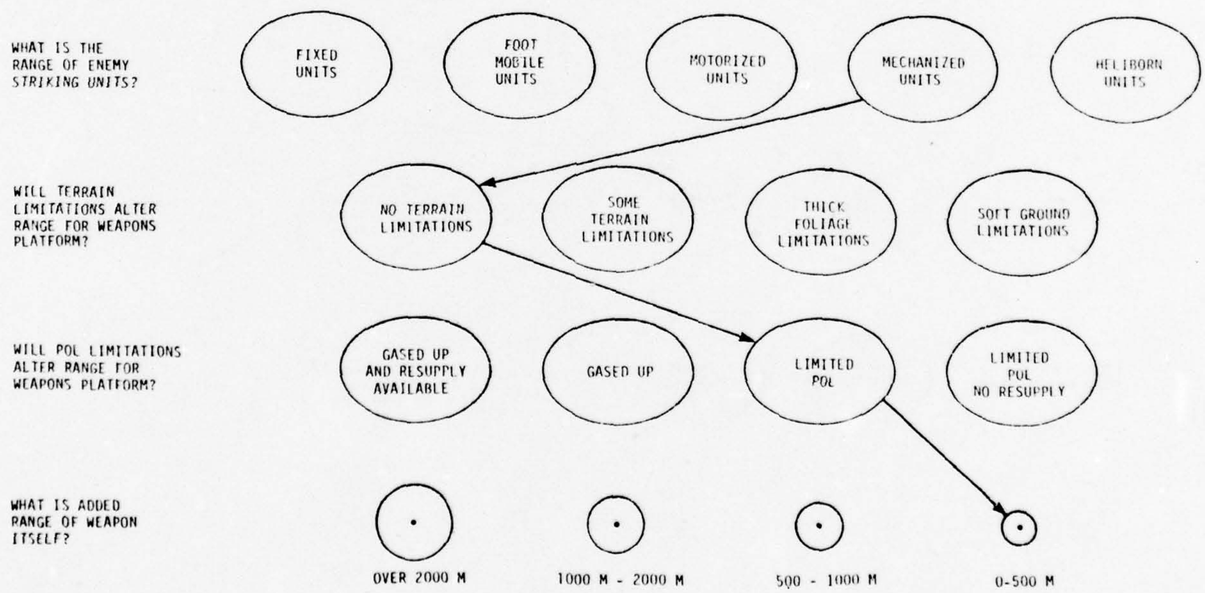
Key Question:

"What is the striking distance of enemy units?"

Rationale:

What an enemy unit can do to us is a function of his mobility and the range of his firepower. It is not enough for the battle staff to be able to know where along their front the enemy is likely to strike; the staff must know the depth current opposing forces can penetrate as their capability changes. Looking at a conventional display there is no indication that a friendly command post is in jeopardy. Defensive responses must be made in-depth when using the active defense.

Data Structure:



7. SOURCE AND ACCURACY OF DATA

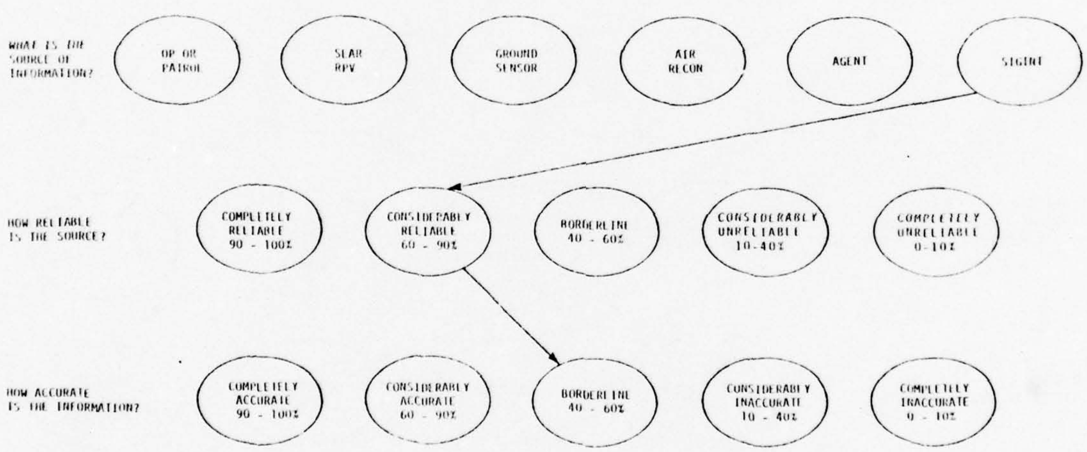
Key Question:

"Which intelligence collection source provided the symbolized information, and what is the current assessment as to the reliability of the source and accuracy of its information?"

Rationale:

The quality of the data displayed remains a critical discriminator for the tactical decision maker. Unfortunately, the current display system has no ready way to annotate the known reliability of the source of information nor the fact that the specific report displayed may have or not have been corroborated by other intelligence.

Data Structure:



8. EARLY WARNING

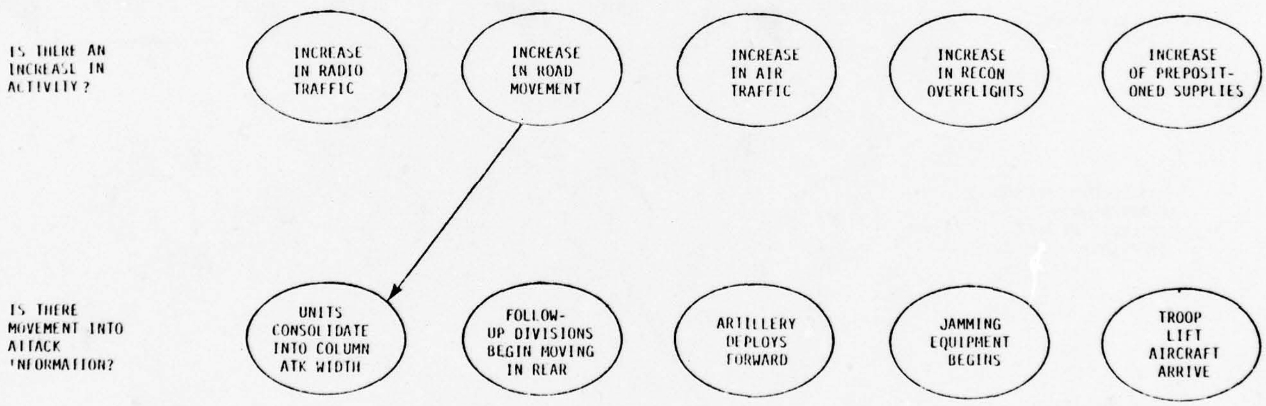
Key Question:

"Are there any critical early moves suggesting a potential enemy attack?"

Rationale:

The concept of the active defense is predicated on early warning. Moving our soldiers to their forward battle positions, drawing the necessary ammunition and meeting the enemy as far forward as possible are the pivotal components for the success of such a tactic. Minutes are critical here and every command staff should be able to see the key indicators as they are reported.

Data Structure:



9. POINT OF PENETRATION

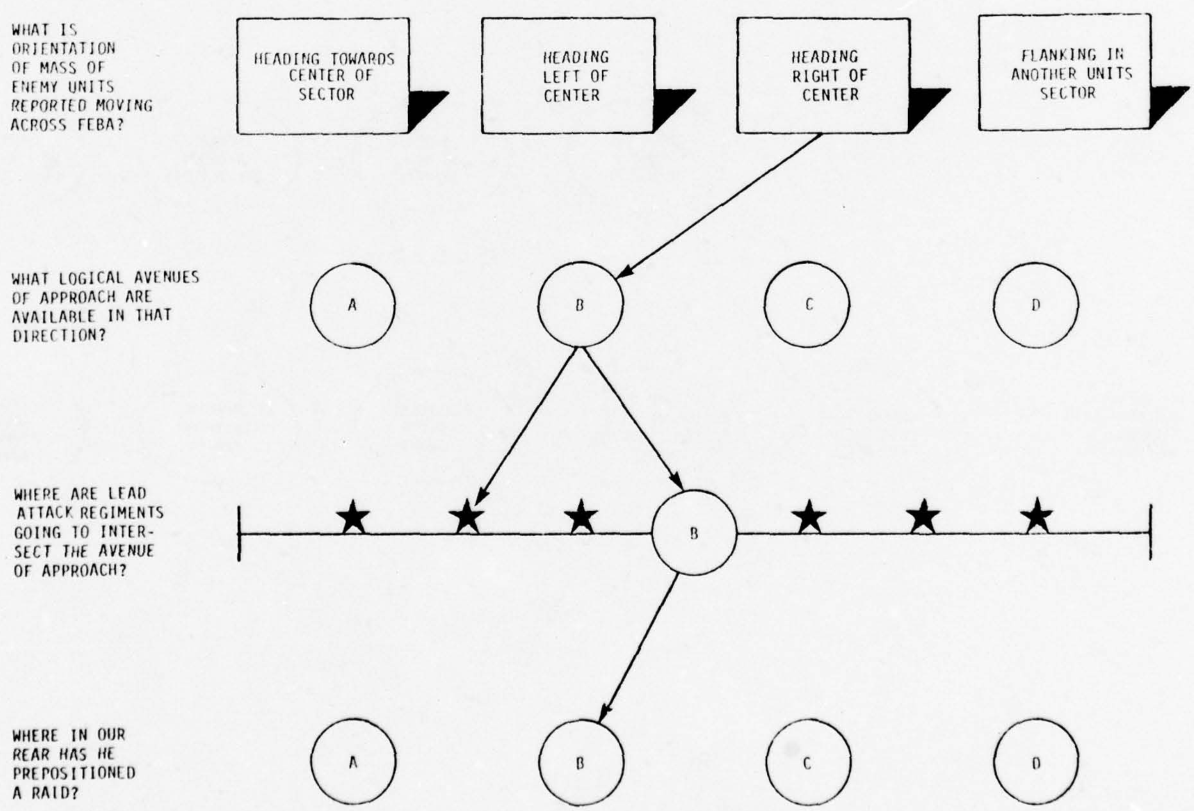
Key Question:

"Where are the likely points of enemy penetration?"

Rationale:

Since it is a known tenant of the active defense that we can only man selected portions of any forward front line, then it is obvious that the defensive positions occupied must include the point of enemy penetration. Therefore, it is critical to be able to clearly see this point on the display system in the early phases of battle.

Data Structure:



10. OBJECTIVE OF PENETRATION

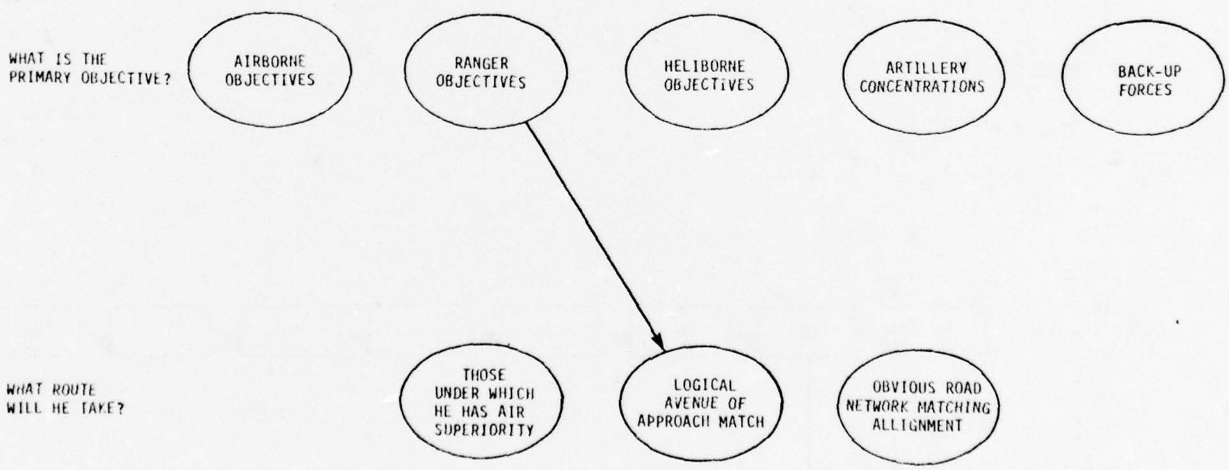
Key Question:

"What is the objective of the enemy penetration?"

Rationale:

Knowing at what point along the line of contact we can expect an enemy penetration is only the first raw data needed to respond tactically. Soon the enemy penetration will take on an elongated shape as it reaches into our area of operations. To properly respond to that threat in-depth, we should be able to anticipate the length, width and azimuth of that penetration. One solid way to assess this is by studying the objectives that would be most lucrative for the opposing force, checking those against their known reach and then plotting the anticipated penetration on a display. In this way, forces can be moved laterally into the breach before the momentum of the penetration makes response impossible.

Data Structure:



11. AREA OF OBSCURATION

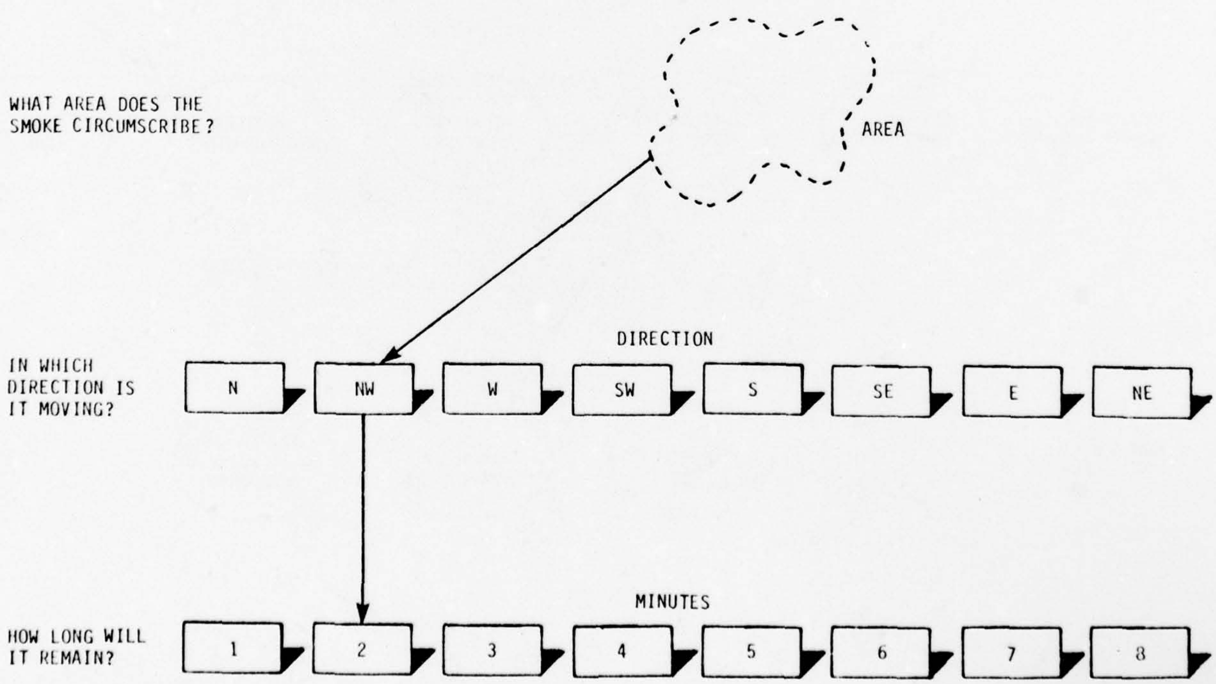
Key Question:

"What areas of the battlefield are obscured by smoke?"

Rationale:

At the fighting echelons below brigade, there are many sophisticated weapons that are designed to work best at ranges up to 3 km. These systems, however, are dependent on the gunner's ability to visually acquire and track enemy targets at that distance. Since the battle staff must recommend where additional weapons of this kind might be used to reinforce our defense, they should be clearly aware of where they will be most effective. So, if the display could reflect those portions of the battlefield currently obscured by smoke, dust, or fog then good locations of where to employ these weapons would surface. This situation applies to the employment of other systems like gunships or CAS (close air support) as well. The obscured areas dimensions and longevity would be useful.

Data Structure:



12. INTERVISABILITY IN METERS

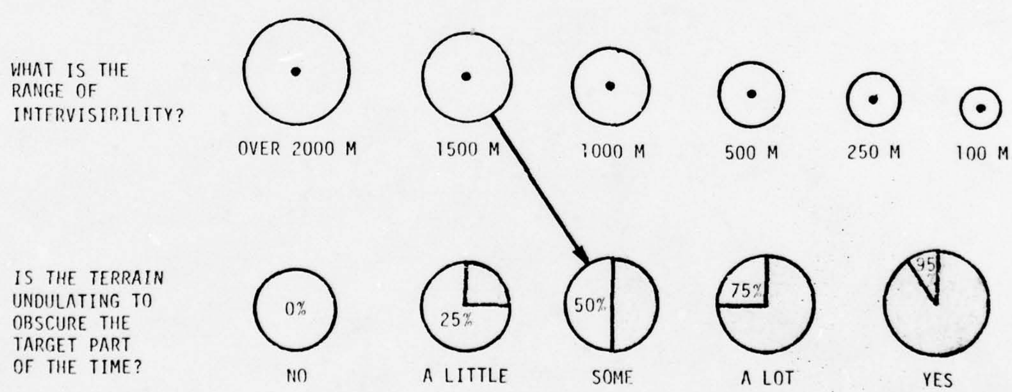
Key Question:

"What is the current intervisibility for our direct fire weapons?"

Rationale:

In concert with the display of any major area of obscuration, it is important to know the intervisability characteristics of every known avenue of approach. One can only shoot as far as one can see. Defiles, trees, built-up areas and many other factors effect how line of sight really works on the ground. As a commander fights rearward and must analyze engagement locations not previously wargamed, an area intervisability index would be a key source of information in order to intelligently select weapons and match them to terrain.

Data Structure:



13. AIR AVAILABILITY

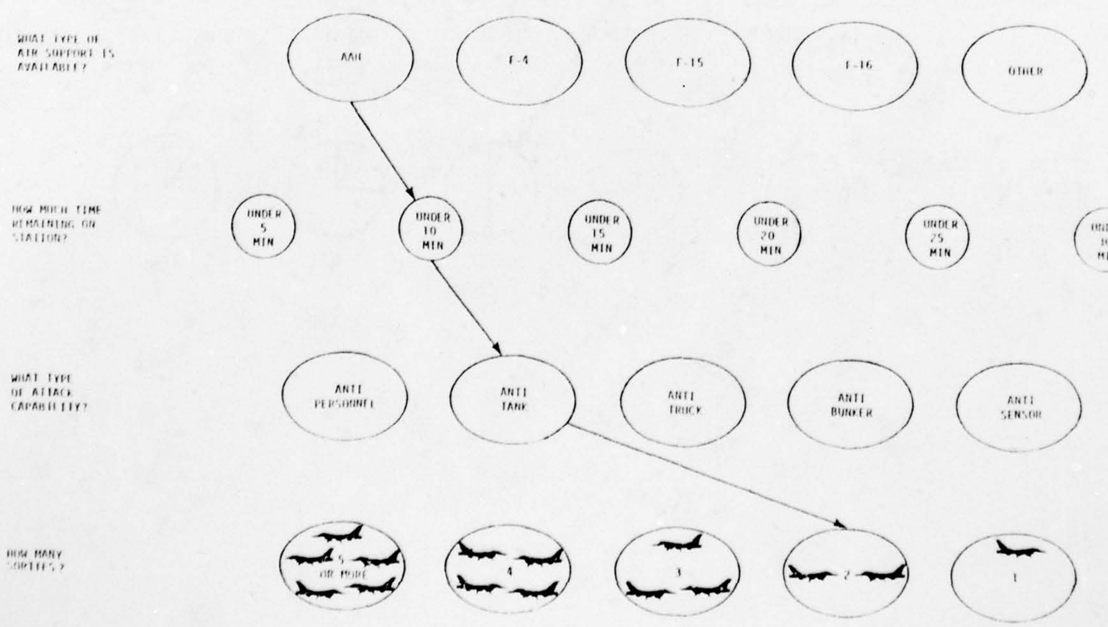
Key Question:

"What is the current station time remaining for our available air assets?"

Rationale:

Often, in the heat of battle, a firepower resource can be overlooked. Close air support, whether from fighter type aircraft or army attack helicopters is a useful resource. But this resource can only hang around waiting to be employed for a limited time. Fuel and enemy air defenses are two reasons for that. The point is that if there were a visual reminder on the battle display system, the staff would probably use these resources well. The reminder need only identify the resource and the time it has remaining on station. If the resource carried any special weapons, that information might also be included.

Data Structure:



14. LATERAL ENGAGEMENT TIME

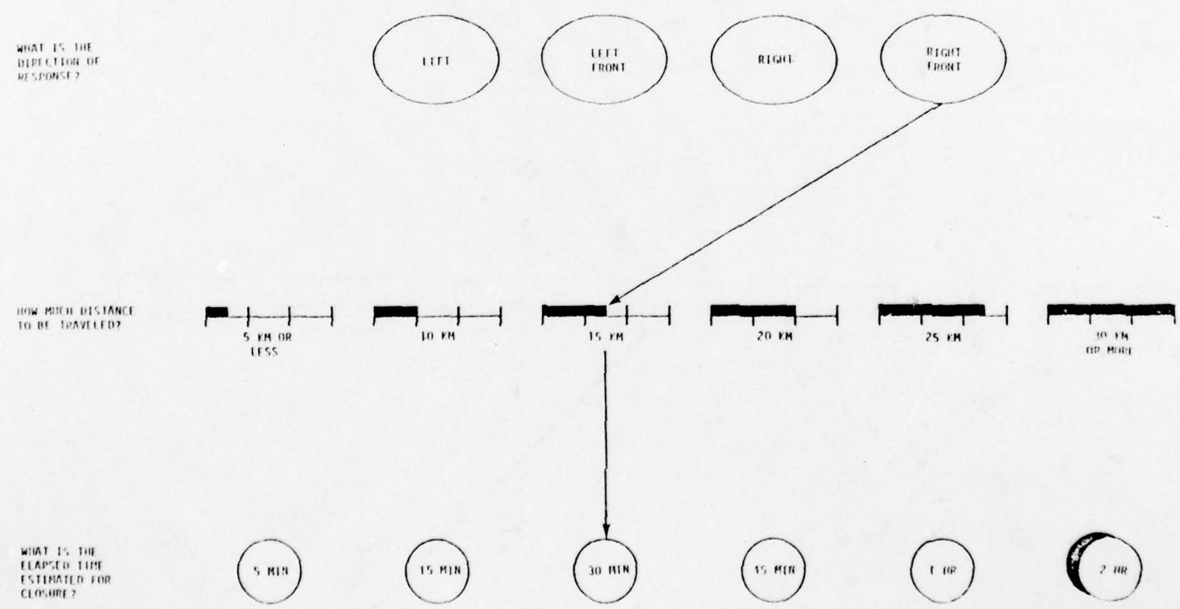
Key Question:

"What is the vector and time of closure for any unengaged unit to move into the breach of the identified penetration?"

Rationale:

In any given sector, the response time for units to move laterally across the battlefield is critical to the active defense. Traditionally lines of communication from front to rear have occupied planners' attention. But, in the active defense one of the fundamental tenants involves the defenders requirement to quickly shift forces, within the battle area, in order to place them directly in front of any enemy penetration effort. Therefore, a relative index by sector for lateral trafficability and mobility expressed in time would be critical.

Data Structure:



15. PREEMPTIVE STRIKE

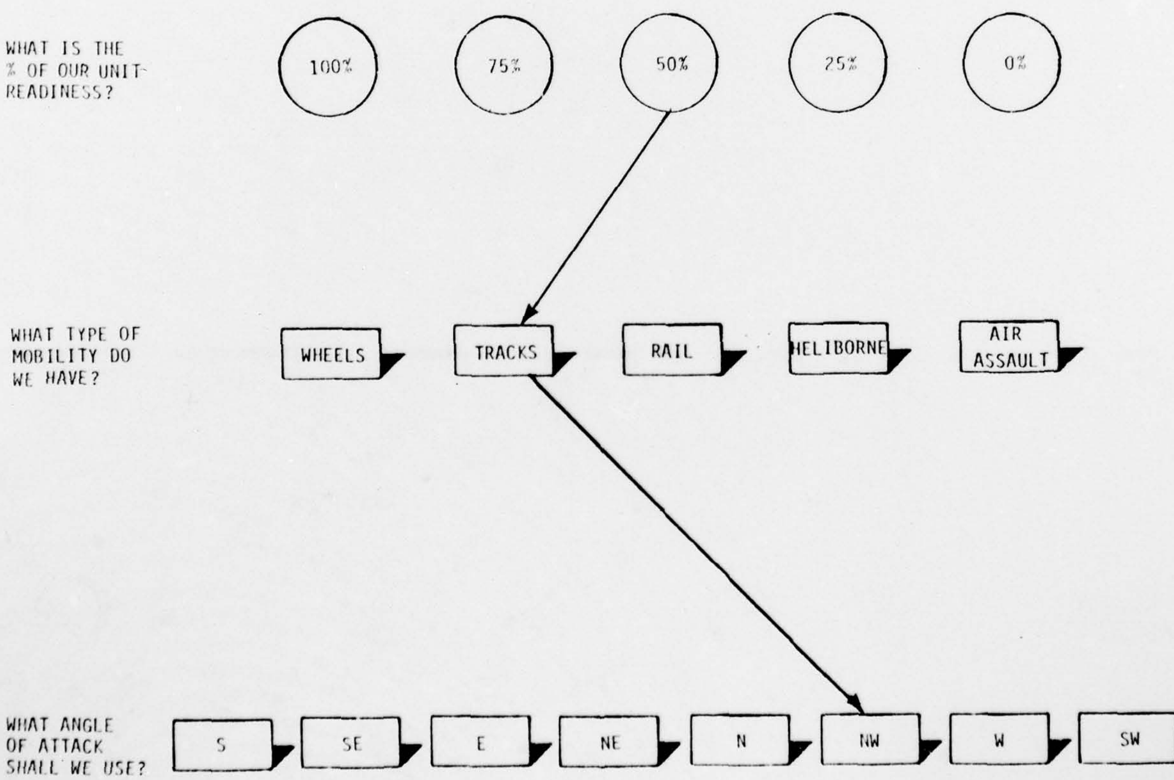
Key Question:

"Can we conduct a preemptive (hasty) attack on enemy forces?"

Rationale:

Should enough early warning be available, a commander might decide to conduct a preemptive (hasty) attack on massing enemy forces or some other critical objective like the control of a key choke point on the enemy's side of the fence. In this case the commander and staff should be able to display their reach and punch as it has been marshalled at that point in time so that they might intelligently weigh the advantages and disadvantages of such a move.

Data Structure:



16. ATTRITION ZONE STATUS

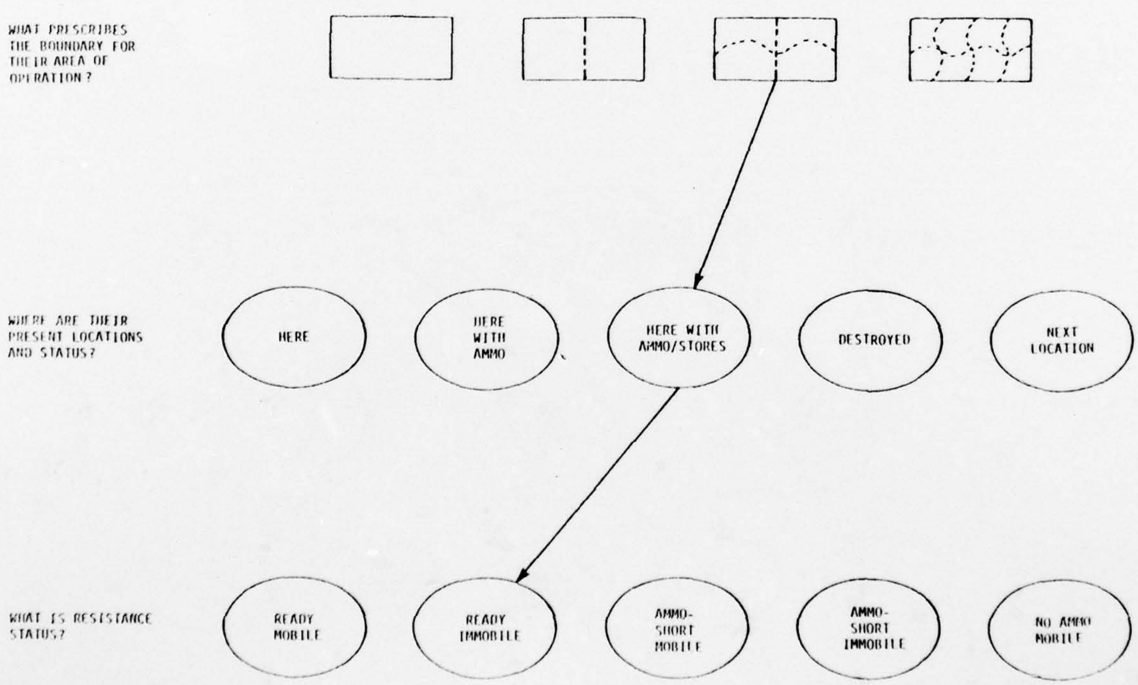
Key Question:

"How can we keep track of autonomous tank killer teams in designated areas of operation?"

Rationale:

An attrition zone defense will include hundreds of small semi-autonomous anti-tank teams. When these teams are deployed in enemy occupied territory, there must be a way of keeping track of teams which are still active.

Data Structure:



17. AIR ATTACK LANES

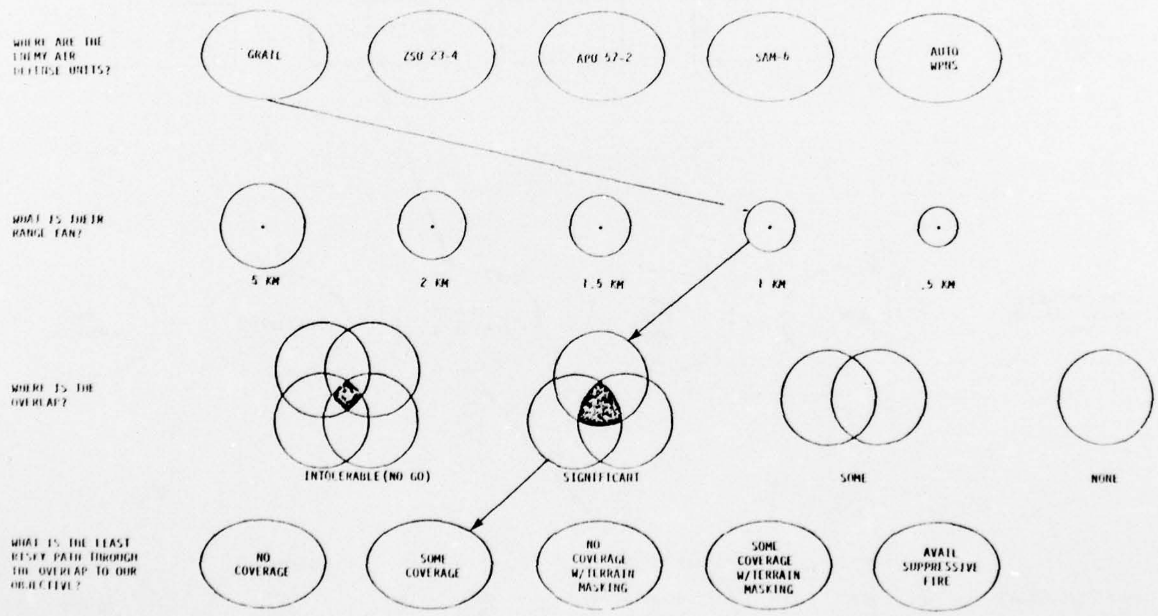
Key Question:

"Where can our aircraft fly to avoid enemy air defense weapons?"

Rationale:

Seeing air defense range fans associated with the enemy units located would aid in identifying the gaps to fly through. The current symbol system allows the identification of air defense artillery units. The critical feature of these units, namely the range of their weapons, is not provided.

Data Structure:



18. MUTUAL SUPPORT

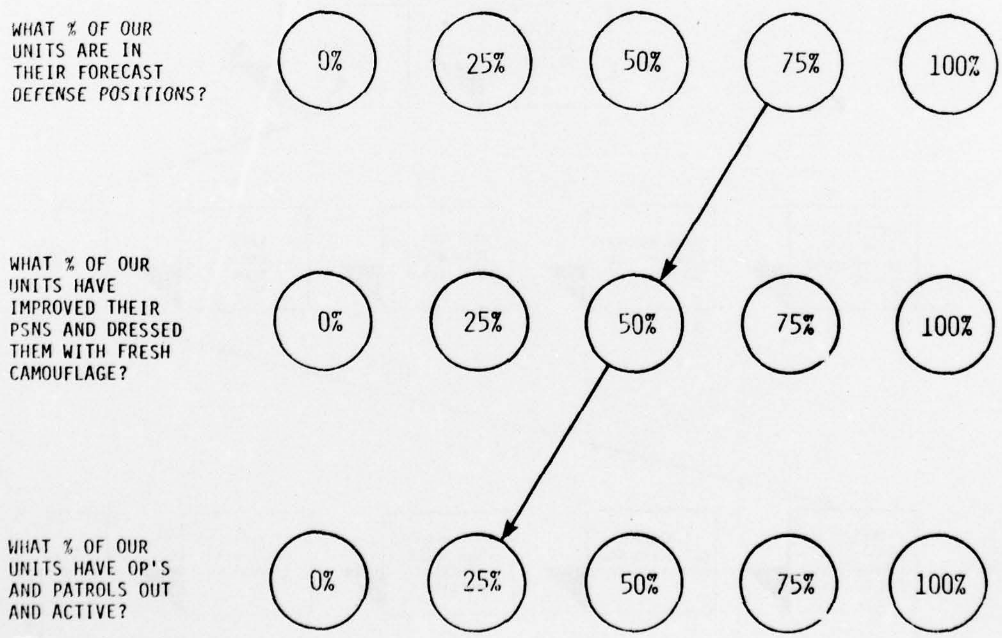
Key Question:

"How do we know if we have the synergistic power of a combined arms team?"

Rationale:

The combat power of a properly integrated mix of combat and combat-support units is significantly more pungent when they work in concert. Ideally, INF, ARMOR, AIR DEF, AVIATION and ENGINEERS are blended to make this kind of combined arms team. Therefore, it would be useful to be able to check the task organization of any unit and evaluate the degree to which those units are in fact combined arms teams.

Data Structure



19. DEFENSE READINESS

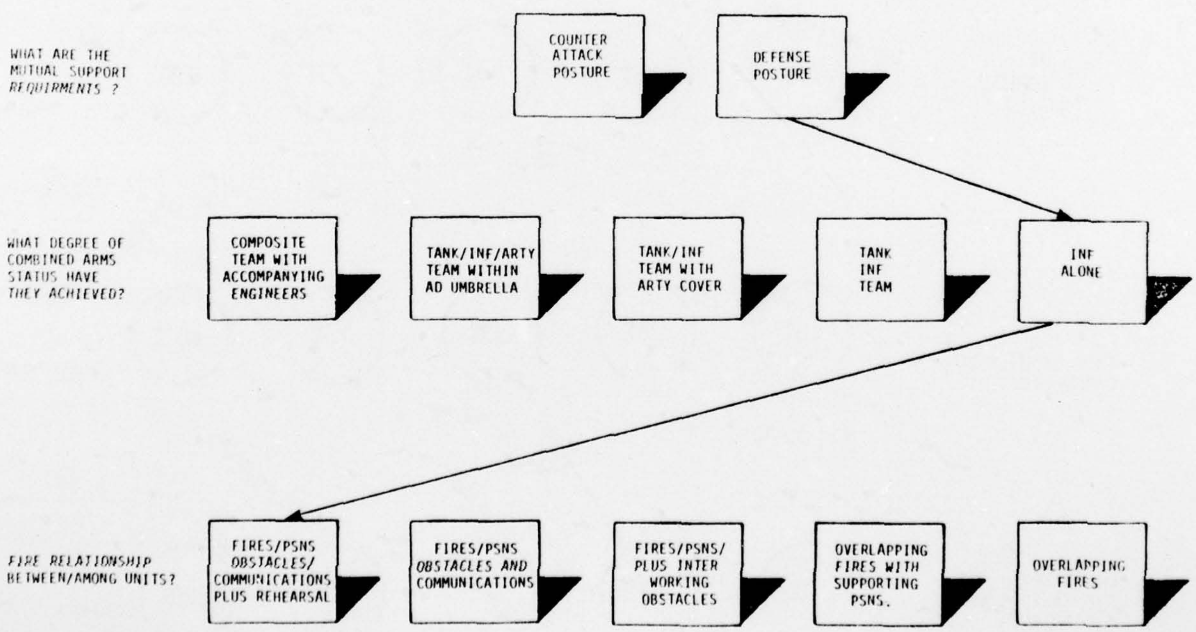
Key Question:

"How do we know the relative defensive readiness of our units at a glance?"

Rationale:

Since we may be fighting outnumbered and outgunned, it's important to have an assessment of the readiness of our units. Some simple rating scheme could be devised to rate the degree to which our units had gotten to their defensive position and begun digging in. Ideally, the units won't get a full readiness mark until they are preparing positions and have dispatched recon patrols and OP's.

Data Structure:



20. TYPE OF AIR THREAT

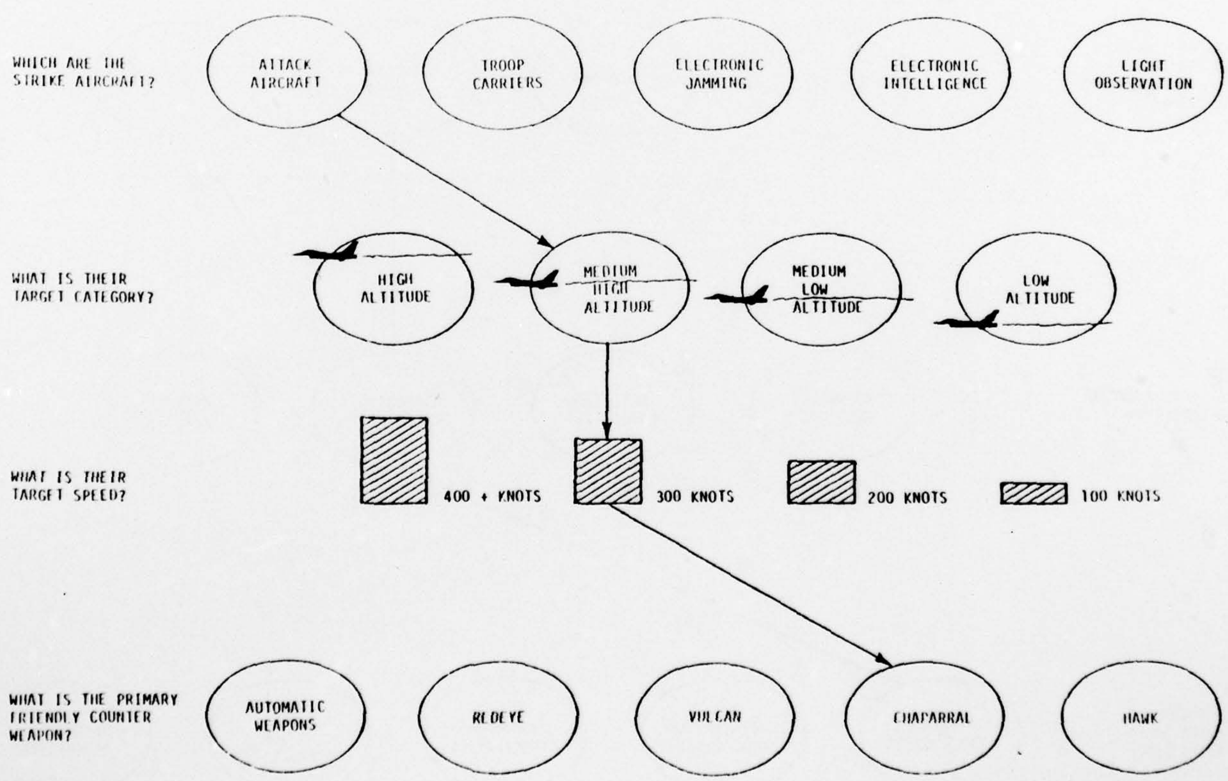
Key Question:

"How can we counterpunch enemy aircraft if we don't know what type are coming?"

Rationale:

Getting alerted to enemy attack aircraft is important. However, the real requirement then is to match the attack aircraft with the corresponding ground counter-punching system.

Data Structure:



21. AUGMENTATION

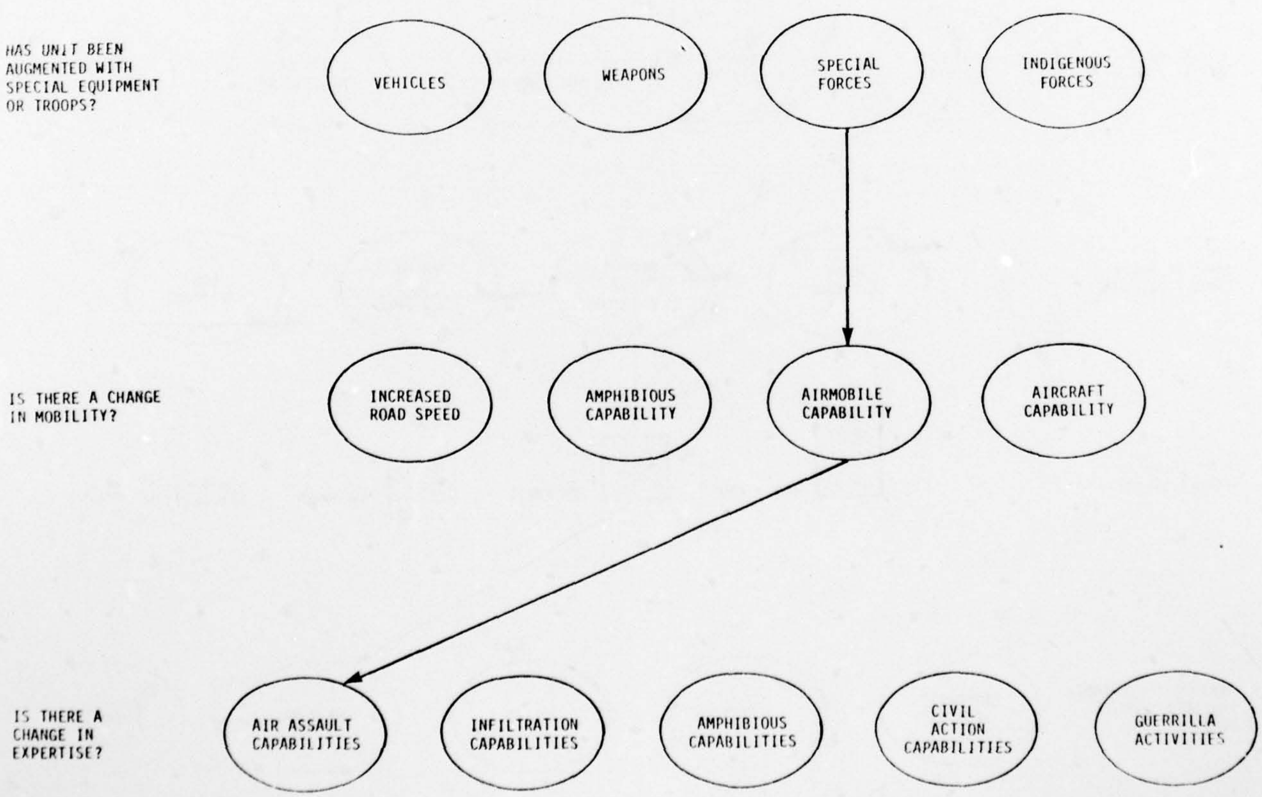
Key Question:

"How can we show when an enemy unit has been augmented with special equipment or special troops since it may tip-off expected missions?

Rationale:

Ocassionally enemy units have been issued special equipment or troops that become a clear tip-off as to their next type of mission. Usually, these augmentations can be expressed in terms of a change in mobility or a change in firepower.

Data Structure:



22. BATTLEFIELD MULTIPLIERS

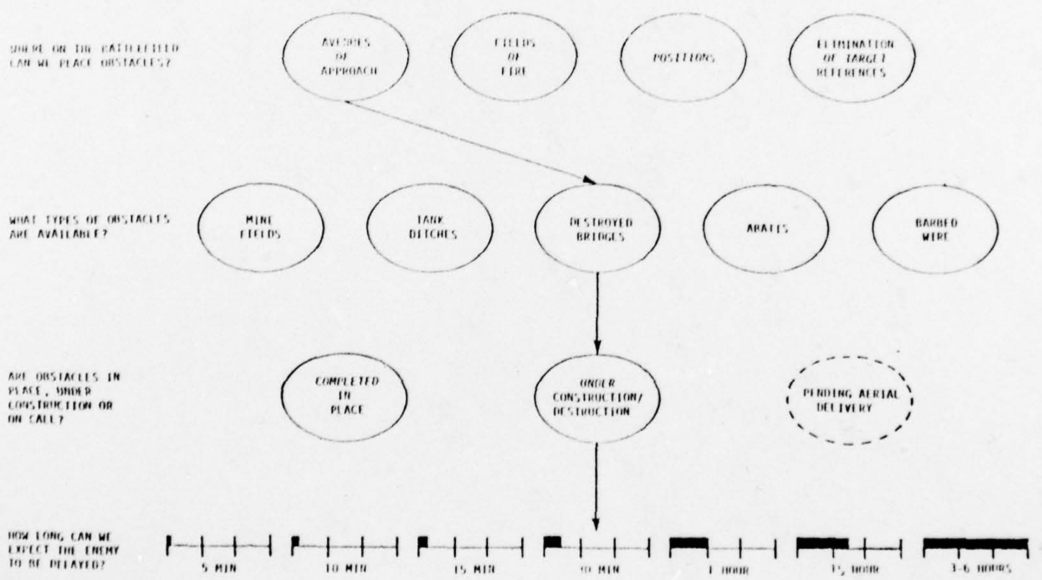
Key Question:

How can we show our actions to thwart enemy movement by obstacles constructed on the battlefield?

Rationale:

A key concept in destroying a massed tank formation is that of placing "glue" on the battlefield. Glue can be mines or obstacles of any sort that allow the period of target servicing to be extended. So any depiction of fires should include both the means used to keep the enemy within the kill zone and the expected delay factor.

Data Structure:



4. A BEHAVIORAL ANALYSIS OF SYMBOL DESIGN EFFECTIVENESS

4.1 Overview

The impact of modern symbology on tactical decision making will depend, to a large extent, on how readily it can be perceived and how easily it can be interpreted. Unfortunately, our knowledge of the principles underlying effective symbol design is rather limited. The following quote aptly summarizes the current situation:

> *"The universal criticism . . . was that there was lots of hardware information but no criteria upon which one could base a sound design. Though one could learn all about the size and brightness of various displays, one could not form any judgment about how effectively the display transferred information to an observer."*
>
> *-from the Preface of Perception of Displayed Information by L.M. Biberman, 1973*

One objective of this chapter is to offer a set of guidelines for optimizing symbol design effectiveness over a wide range of user-based performance criteria. Each guideline will be in the form of a "design rule" for meeting a prescribed set of behavioral criteria. For example, a guideline for enhancing symbol discriminability might be: *Minimize the visual similarity of design features among members of the same symbol set.* Our first step in the derivation of such guidelines was to identify the same fundamental behavioral skills that are essential to the effective use of symbology. We reasoned that a taxonomy of relevant behavioral criteria would provide a coherent basis for organizing the available research literature and deriving guidelines for symbol design. As it turns out, similar--or even identical guidelines--occasionally result from the analyses of the different behavioral processes.

A behavioral taxonomy was developed by analyzing a typical sequence of tactical task requirements. These requirements were embedded within a task "scenario" developed in consultation with experienced military symbol users. Each task described in the scenario was used to identify a corresponding set of user-based behavioral requirements. The resulting taxonomy was then used to organize a selective review of the literature in visual perception, cognitive psychology, and human factors. Finally, basic empirical findings in each task-related area (e.g., visual discrimination) were used to evaluate a sample of current symbol design candidates and formulate tentative guidelines for improving symbol-use performance.

The development of a behavioral taxonomy through analysis of a task scenario is a plausible procedure; but a useful set of behavior requirements could, in our view, be alternatively derived from an inductive analysis of a variety of literature sources. These sources include behavioral and military literature, studies on the development of a taxonomy of human performance (see Fleishman, 1975 for a review), as well as additional literature in cognitive psychology. As an illustration, a tentative taxonomy was derived using this alternative method, and it is presented in Appendix D.

4.2 Behavioral Requirements

A sample task scenario was developed to provide a concrete description of the symbol-use process and a realistic context for the present psychological analysis. This scenario was based on conventional symbol-use tasks (as listed in Table 2-1) and was designed to reflect a rather typical pattern of interaction between a symbol user and a standard situation display. As illustrated below, the task selected for analysis is a relatively complex one and involves many important elements of the symbol-use process.

Task Requirement: *Determine where the enemy is likely to conduct his breakthrough attack.*

Task Scenario: *The situation map is scanned to locate the preponderance of the enemy's forward combined arms units. This search process is complicated by the fact that attack unit symbols are co-mingled with support unit symbols of various types. After locating a threatening mass of battalions, an acetate attack template is placed over them to see if the formation has adopted the classic attack posture. A check is then made of annotated (textual) reports on the enemy's rear to see if they have connected with the forward concentration. Next, the Order of Battle book is checked to see if the adjacent units had previously participated in maneuvers as a penetration force. Finally, the range and striking distances of these units are calculated using enemy doctrinal manuals, and a line is drawn from suspected attacking regiments to their suspected objectives in our own area of operation. The points where these lines cross the border represent the best guess as to the points of penetration.*

The preceding sequence of events serves to illustrate some of the essential user-based requirements for effective symbol use. The first task requirement is simply to establish the location of "combined arms" units. This requirement, however, presupposes a knowledge of the symbolic code corresponding to each type of combined arms unit. In effect, the user must previously have acquired a vocabulary of symbolic code and learned to translate each element of that code into a corresponding tactical concept. This raises the issue of symbol learnability: What design criteria are associated with ease of learning? Next, the user is required to search through a relatively structured situation display to locate a small set of target symbols: What design criteria are necessary to effectively "cue" the search process and what are the effects of map display background on search efficiency? Another factor complicating the search process is that the user encounters difficulty making discriminations between visually similar combat and support unit symbols: What design features are correlated with ease of discriminability especially on a cluttered situation display?

After completing the search, the user super-imposes an acetate template on the map to enhance his ability to detect an attack configuration. The ability to see complex patterns involving more than a single unit raises still another major issue: Can symbols be designed to facilitate user recognition of tactical formations? After determining the enemy's formation status, the user has to disrupt his visual analysis of the display to obtain related information from a textual source (namely, the recent history and current mobility of enemy striking units). Upon completing this task, another non-display effort is undertaken to estimate the range of enemy weaponry and compute their doctrinal striking range (i.e., their reach). These activities illustrate the time-consuming and distracting nature of tactical questions that cannot, at present, be "answered" using a purely graphic information resource. Such questions clearly have a negative impact on the user by: (1) placing a burden on his limited-capacity short-term memory (since he has to remember and integrate information from both visual and textual media) and (2) requiring him to synthesize or summarize details in order to infer information essential to the on-going assessment process.

The preceding analysis of display-related task requirements has identified a number of information processing problems--both cognitive and perceptual--that may befall the tactical symbol user. The cognitive problems--namely those relating to short-term memory and inference--appear to be partly due to a deficient tactical database and will not be addressed here since they are not strictly a function of deficiencies in symbol design. It should be noted, however, that an expanded database--one incorporating relevant textual data and offering information at multiple levels of detail--might help overcome most of the major cognitive problems posed by the current map/symbol system. The focus of the current analysis, therefore, is for the most part limited to perceptual problems arising from built-in sensory and/or capacity limitations of the user.

Symbols can and should be designed to complement rather than inhibit the processes of discrimination, search, and learnability. These three processes--each manifested in the preceding task scenario--represent basic behavioral requirements of the tactical symbol-use process. Symbol designs might be judged effective to the extent that they can maximize performance along each of these fundamental task-related dimensions. Design features that are correlated with ease of learning, for example, may or may not minimize confusability during symbol discrimination.

A more detailed model of behavioral requirements is presented in Figure 4-1. This scheme will be used to organize the following discussion of major psychological issues in symbol design effectiveness. The objective is to derive preliminary design guidelines for enhancing performance along each of the major psychological dimensions. Each guideline is obtained by evaluating current symbol design candidates in the context of available psychological knowledge. An analysis of concrete symbol use "problems" should help to stimulate the development of remedial strategies for overcoming or minimizing perceptual bottle-necks in the symbol-use process.

4.3 Discriminability

4.3.1 Overview. The ability to visually distinguish among members of a symbol set represents a basic component of the symbol-use process. The ease with which such distinctions can be drawn often depends on the distribution of feature similarity among members of the symbol set. It is well-known, for example, that ratings of visual similarity can be used

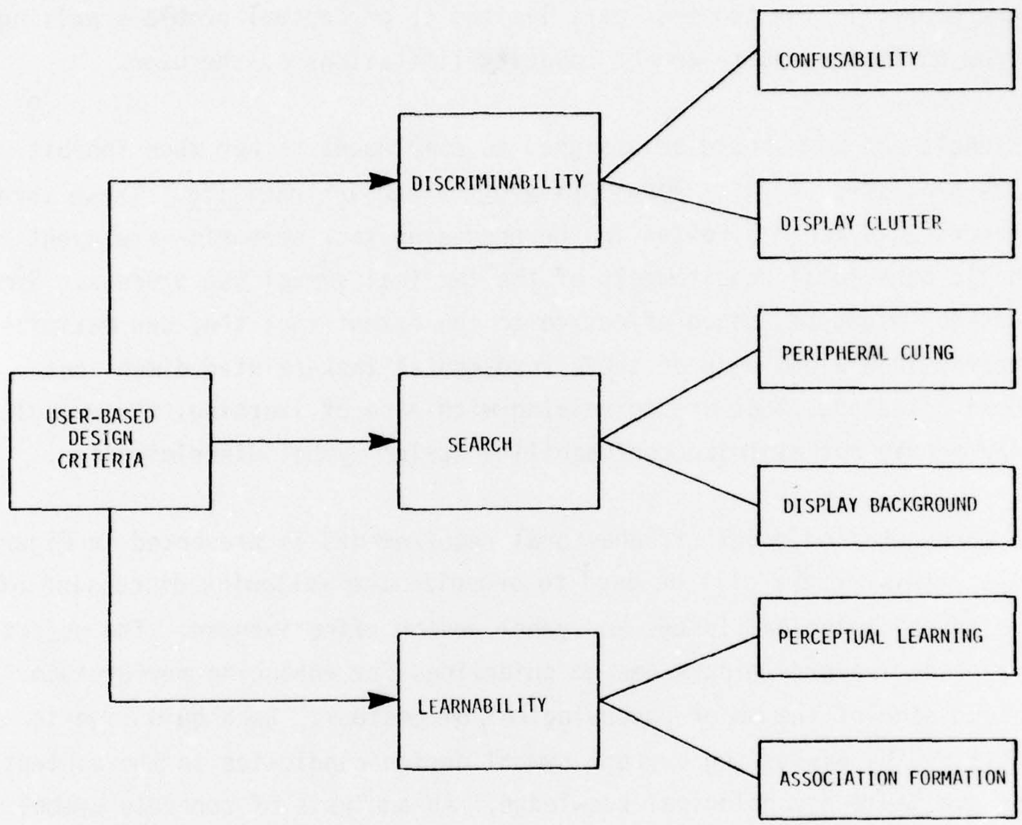


FIGURE 4-1. PSYCHOLOGICAL DIMENSIONS OF THE SYMBOL-USE PROCESS

to effectively predict performance on a test of symbol discriminability (e.g., Cannon, 1977). For purposes of the present discussion, two related issues in visual discrimination are considered. The first concerns an impairment in discrimination due to feature similarity (referred to as "confusability"), while the second concerns a related performance impairment due to feature competition (or, in the present context, "display clutter"). The discussion of symbol confusability includes a brief statement of the strengths and weaknesses of using different general types of codes (iconic, color, alphanumeric, or multidimensional).

4.3.2 Confusability. A high degree of feature redundancy among members of a symbol set is known to impair discrimination both in terms of confusion errors (Cannon, 1977) and response latency (Egeth, 1966). For example, the lines forming the perimeter of each symbol in Figure 4-2 contain identical visual features. Therefore, for the purpose of discriminating unit function, the "box" that surrounds each symbol seems to place an unnecessary processing burden on the user. The user's discrimination task is made more difficult (especially at the periphery) and, coincidentally, the features in question convey absolutely no tactical information. This perceptual problem is further compounded by the fact that the visual system is most sensitive to box-type features because of their horizontal and vertical orientation (Dodwell, 1970). In summary, the box format of conventional FM 21-30 symbology may impair the identification and/or discrimination of unit function by maximizing similarity among visually salient design features. For this reason, it may be noted that current Army development concerning tactical symbology have endorsed and experimented with "boxless" conventional symbols (see Sidorsky, Gellman, and Moses, 1979).

The preceding analysis suggests the following tentative design guidelines:

> (1) *Minimize, to the extent possible, the amount of feature similarity among different members of a symbol set.*
>
> (2) *Minimize the perceptual saliency of the features that must remain redundant across members of a symbol set.*
>
> (3) *Maximize the discriminability of those graphic features used to code important tactical information. For example, horizontal and vertical lines should be more salient than those with an oblique orientation.*

The perceptual analysis can be extended to include those features residing in the interior of each symbol. It is well established that thick lines conveying basic "shape" information are perceptually more salient than thin lines conveying fine "detail" (Yoeli & Loon, 1972). Thus, the thick lines depicting "military police" in Figure 4-2, will be more easily perceived than the thin lines representing either infantry or armor and this discrepancy will increase the more peripherally they are viewed. Obviously the differential salience among these unit representations does not reflect realistic task priorities. Now consider the armor symbol in Figure 4-2 which has been filled-in. This simple modification increases its visual salience above that of the military police symbol. The point to be made here is that a perceptual analysis of symbol design features can help to operationally specify criteria for enhancing performance in symbol-use tasks.

Extensive research effort has been directed toward the understanding of the perceptibility and discriminability of different types of display symbols in portraying tactical information (for an independent review, see Shackel & Shipley, 1970). The types of codes that have been examined include iconic codes, color codes, alphanumeric codes, and multidimensional codes. The strengths and weaknesses of using each of these types of codes in a new symbology will be discussed in turn.

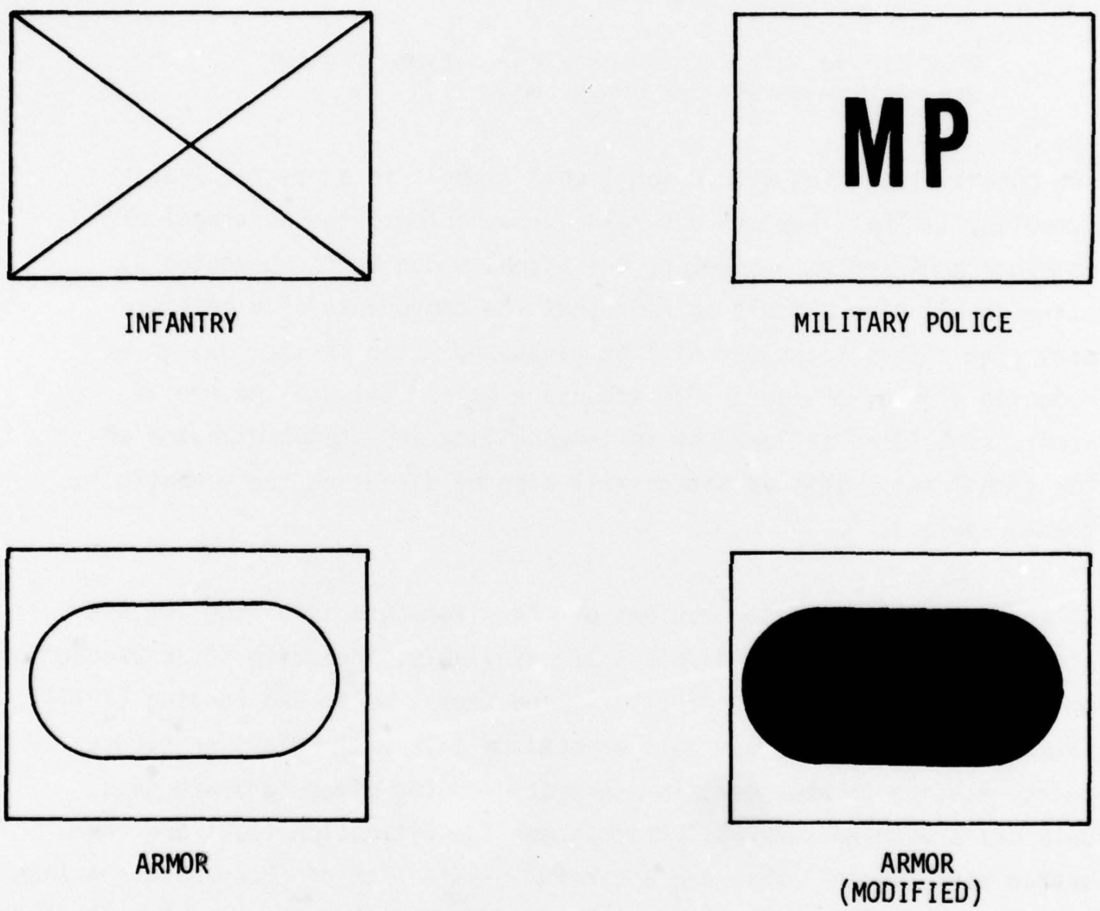


FIGURE 4-2. CONVENTIONAL SYMBOL DESIGNS (FM 21-30)

Iconic Codes. Iconic symbols have been found to be recognized more accurately and more quickly when (a) they are filled in as compared to when they are open (Chainova, Komarova, & Zonabend, 1974; Yoeli & Loon, 1972), and (b) when they are drawn as simple silhouettes, without great detail (Chainova et al., 1974; Foley and Wallace, 1974). Therefore,

> *When iconic symbols are used, solid forms without unnecessary detail are preferred.*

One potential problem with using iconic symbols in a new tactical symbology is that they are not readily amenable to the portrayal of combined arms forces. However, this problem can be circumvented by using overlapping symbols to represent the components of a combined arms army. This technique will be discussed later in the context of reducing display clutter. One advantage gained through the use of iconic symbols is an increase in learnability and standardization of the symbol set. This advantage will also be discussed subsequently in greater detail.

Color Codes. A few major reviews of the literature involving the use of color codes in visual displays are available, including those prepared by Christ (1975), and Wagner (1977), and Krebs, Wolf, and Sanding (1978). Christ reports the minimum loss or maximum gain with colors as target codes relative to when certain achromatic coding dimensions are used. Data are presented separately for target identification tasks and for search performance tasks, and a careful examination of these data combined with cost considerations should help in deciding when to use color displays. Christ concluded that colors can be identified more accurately than shape or form parameters, especially with cluttered displays (Christ & Corso, 1975), but less accurately than alphanumeric symbols. Wheatley (1977), on the other hand, found that numeric symbols also comprise a less salient dimension than color. On the negative side, Christ reported that irrelevant colors in a display have been seen to interfere with a subject's ability to identify achromatic target features.

In an investigation by Sidorsky (1976), a number of coding schemes were tested in tasks of varying complexity in which operators had to manipulate certain tactical elements. The major conclusion was that color coding is of some benefit in terms of processing times and error rates, but only if color aids the analyst in the initial grouping of the symbols. Thus, Sidorsky's conclusions were similar to those of Christ (1975) that color can help in identification and searching tasks; but color has little effect on, and might actually degrade performance in tasks that depend on non-color properties of the symbols as well.

In a recent design for color displays, Krebs et al., (1978) summarize the situation as follows:

> *The question of whether or not to use color in various display applications is currently one involving some controversy. Data that can support either side of the issue can be selected from the literature. A careful review and analysis of the color literature reveals that the issue of color utility is not a simple one. The value of color as a coding method is entirely dependent on its effective use in a specific application. That is, it can be beneficial, neutral, or distracting. Which of these outcomes will occur is a function of how, where, and when it is used. The operator task, the environment, the display medium and the specific way in which color coding is applied are all important. (p. 1)*

However, with respect to tactical symbology, it seems reasonable to advise that:

Color codes, because of their apparent ability to differentially enhance symbol saliency, should be used to denote the most important or most frequently used tactical information.

In general then, the use of colors to represent information in symbolic displays has met with mixed success. In this regard, Wong and Yacumelos (1973) found that accuracy and speed in identifying symbols from a map-like display was not affected by whether the map was displayed in color or in black and white. Nevertheless, subjects usually find color displays to be less monotonous (Christ, 1975).

Alphanumeric Codes. Nawrocki (1972) found that in tasks where performance was not heavily dependent upon a subject's memory, displays using alphanumeric symbols resulted in faster and more accurate identification performance than did displays involving standard military symbols (FM 21-30). Though Nawrocki did not consider other forms of geometric codes, Christ (1975) also noted an advantage of alphanumeric symbols in his review paper. In addition, Weltman and Helgesson (1972) found that lower-case letters are more discriminable than upper-case letters. This is probably because lower-case letters show greater variability in shape. Thus,

When letters are used, perhaps to annotate geometric display symbols, lower-case letters should be used to improve discriminability.

Multidimensional Codes. Ericksen (1954) found that multidimensional symbols are more easily discriminated than are symbols that differ on a single dimension. The dimensions used were size, hue, and brightness. Also, Wheatley (1977) demonstrated that abstract information such as threat can be judged more reliably when represented in multidimensional form, though subjects usually perceive one of the dimensions used to be most salient. Andrews, Vicino and Ringel (1968) have noted that the perception of updated information as such in a battlefield display is superior when two alterations are made in symbols representing changed information rather than just one. This is especially true when the amount of information presented is increased (Vicino, Andrews, & Ringel, 1965). These results suggest that multidimensional symbols are preferable to unidimensional symbols; but much difficulty has been encountered in defining enough dimensions to display relevant information. Hence,

> *Given that a sufficient number of dimensions are available to portray required information parameters, multi-dimensional display codes are desirable.*

The use of redundant codes, consequently, may not be possible in an efficient, information-rich tactical symbology.

4.3.3 Display Clutter. As noted by Potash (1977), many investigations of behavioral considerations lack generalizability because only one aspect of a display is examined in isolation, whereas symbols must certainly interact in the context of the total display. One of the most common criticisms of current tactical displays is the problem of clutter. The cluttered appearance of battlefield displays makes the rapid extraction and comprehension of tactical information difficult (e.g., Middleton, 1977a).

In dealing with the problem of clutter, some researchers have noted methods to avoid it, whereas other researchers have suggested ways to overcome it. To avoid display clutter, Simonsen (1977) has argued for reduced detail in the display symbols used; and Channon (1976) has suggested that only critical units be portrayed. The critical units would most often be the maneuver units with the support units noted only in abbreviated, or summarized form. To overcome display clutter, Andrews and his associates (Andrews & Ringel, 1964; Andrews, Vicino, & Ringel, 1968) have suggested that important battlefield changes might be double coded to increase their perceptual salience. Also, Christ and Corso (1975) have concluded that the use of color improves search and identification performance when clutter exists.

The most obvious solution to the problem of clutter is, of course, to simply increase the size of the display used. Oversized maps would allow for greater detail without additional clutter. However, since there are practical limitations on the maximum size of a display used in conjunction with an automated data processing system, the user can necessarily view only part of the map at a time. The effects of this limitation on the internal representation of maps has not been studied extensively (Jansses & Michon, 1973). Furthermore, there is a consensus of opinion that the clutter problem is particularly acute when using automated grahics systems. In fact, the transition to ADP systems depends, in part, on a viable resolution to the clutter problem.

When a number of characters, symbols, or shapes are simultaneously present in the visual field, they usually interfere or "compete" with one another (e.g., Mackworth, 1965; Estes, 1972). Furthermore, the degree of interference among characters increases with their feature similarity (Bjork and Murray, 1977) and foveal eccentricity (Mackworth, 1965). This interference effect can be simply understood in the following manner. Structural components of the visual processing system seem to be adapted for detecting specific visual features. In addition, the evidence suggests that each specialized feature detector has a limited capacity for the number of characters it can process at a given time (Bjork and Murray, 1977). Since symbols containing similar features draw on common limited-capacity feature analyzers, visual similarity increases the interference and "clutter" arising from adjacent characters. A clear demonstration of this is that the identification of a single letter presented on a CRT display can be reduced to nearly chance levels when two instances of the same letter are simultaneously presented in adjacent positions, i.e., the presence of one letter can inhibit the detection of the other.

The preceding discussion suggests a number of important implications for designing symbols that attempt to convey tactical information along more than a single dimension (e.g., function along one dimension and capability along another). In particular, to reduce the perceptual clutter of a battlefield display, it seems desirable to:

> (1) *Minimize the visual similarity among design features corresponding to different tactical information dimensions. For example, in order to code mobility vs. firepower information, features should be selected at different orientations to minimize visual interference among symbol components.*
>
> (2) *Maximize the distance - within each symbol - between similar visual features because interference due to visual similarity decreases with distance.*
>
> (3) *Minimize the graphic detail in the symbols used.*
>
> (4) *Portray only critical units in the display.*

Interference due to visual similarity among adjacent symbols increases in the periphery of the visual field. This interference has been shown to produce a "tunnel vision" effect (Mackworth, 1965). The user viewing a display containing numerous similar symbols will be able to extract crucial tactical information only when he fixates directly on its display location. For example, the feature similarity of FM 21-30 "box" symbols is particularly effective for producing this tunnel vision effect. The undesirable consequences of this problem are especially apparent when searching the display to locate a specific item of information. The following quote by Mackworth (1965) describes the general impact of feature similarity on a display search task:

> *"Selective visual attention usually involves direct movements of the fovea from one rich source of data to another. The most frequent choice ever made is where to look next. The fovea is such a busy sensor that it has to sample only essential data almost*

> *continuously. To reduce random search, eye movements must often be planned from data acquired by the peripheral retina. The main contention is that the addition of visual noise in the form of unwanted signals can destroy the vital peripheral matching. Pattern recognition is impaired because similarities can no longer be recognized quickly between wanted foveal and peripheral items - and the fovea must therefore be used more often."*

In summary, the research literature suggests that visual similarity within as well as between tactical symbols, generally impairs search by reducing the discriminability of peripheral design features. A more detailed discussion of the symbol search process is presented in the next section.

An issue related to the problem of display clutter is the information and computational overload experienced by the user of a tactical display. Information overload appears when the amount and detail of tactical information presented to a commander exceeds his information-processing capacity. This can occur even when viewing a clutter-free display, since information overload describes a burden on higher-level cognitive processes and not on lower-level perceptual processes. A case in point is the processing of updated information, which becomes more difficult with a greater number of battlefield changes (Andrews and Ringel, 1964). Computational overload pertains to the number of computational steps required to convert information into plans for action. For example, Rosenberg (1978) has noted the multitude of procedural steps that must be followed to estimate relative combat power. Therefore, an additional suggestion toward the construction of a more useful tactical display symbology is to:

> *Develop summary symbols, and symbols that represent important tactical indicators, to reduce the number of computational steps required in pre-decisional processing.*

4.4 Search

4.4.1 Overview. The objective of this section is to provide an analysis of symbol design criteria as they interact with the visual search process. As a vehicle for analysis and discussion, we will focus on Tactical Capability Symbology (TCS) developed by Sidorsky at the U.S. Army Research Institute (ARI). The first issue addressed is the impact of peripheral discriminability on the visual search process. Next, the effects of display background on the selection of an efficient search strategy are considered.

4.4.2 Peripheral Cuing. Visual search performance appears to be heavily dependent upon the peripheral discriminability of symbol design features (e.g., Bloomfield, 1975). That is, the search process is viewed as a systematic series of eye fixations where the location of each fixation is cued or guided by peripheral perception of the visual features processed during a previous fixation (Erickson, 1964; Johnston, 1965; Bloomfield, 1970). Symbol design efforts, therefore, could benefit from a knowledge of the detectability and discriminability of graphic features in peripheral vision. Furthermore, peripherally discriminable design features should be used to code those tactical concepts which most often motivate the visual search task (e.g., unit function).

To illustrate, let's examine the extent to which some TCS design features, shown in Figure 4-3, function as peripheral cues during search. The goal of TCS (See Section 2.3.1) is to portray tactical information along a number of orthogonal design dimensions. For example, the outer circle is used to code various aspects of unit capability (e.g., threat, mobility, logistics, etc.) while the interior of the symbol conveys unit function. As mentioned above, research suggests that thin or dotted lines are significantly less salient than thicker solid lines (e.g., Yoeli & Loon, 1972). The implication for TCS is that "division" symbols (solid circles)

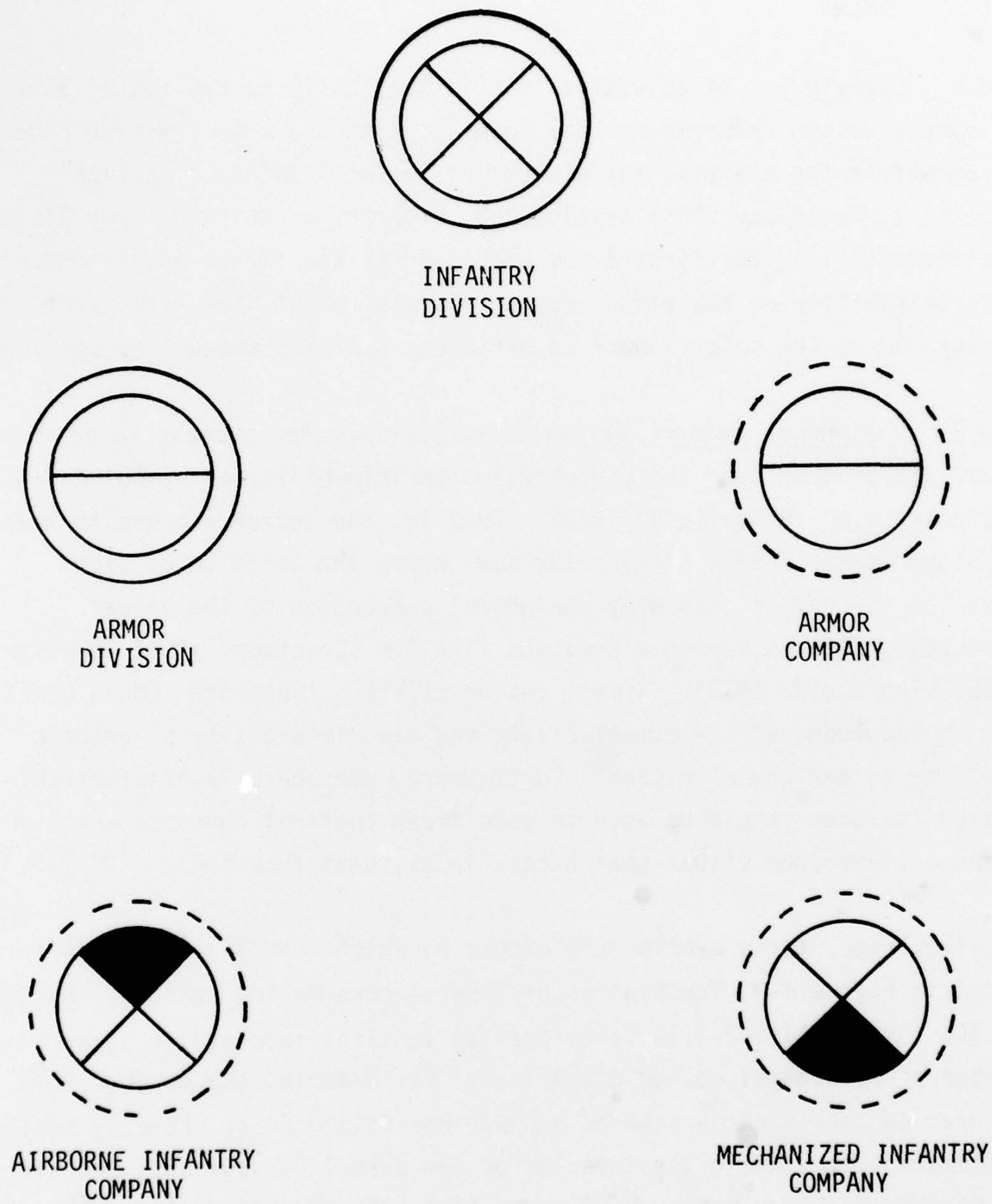


FIGURE 4-3. TACTICAL CAPABILITY SYMBOLOGY (TCS)

are more likely to be discriminable in the periphery than "company" symbols (dotted circles). This is entirely consistent with the assumed task priority of locating larger tactical units. The use of solid lines to represent the division level, however, may impair the peripheral detectability of important functional information (located in the interior of the symbol). The reason is that solid outer lines are visually salient and may effectively define basic shape information in the periphery of the visual field. The use of dotted lines to represent companies, on the other hand, would probably not impair the detection of function as much since their outer circles are less salient and play a smaller role in determining symbol shape.

In the example just considered, it turns out that a choice was made, either implicitly or explicitly, to emphasize the peripheral detectability of unit size. This decision can be rationalized quite easily since the search process should be directed toward the identification of larger or more important tactical units. The advantage given to the size dimension, however, was "paid for" by decreasing the peripheral salience of functional information. Fortunately, this presents no problem to the symbol user who has located a division level symbol since the user can easily perform a functional discrimination using foveal vision. Design trade-offs such as these will need to be clearly defined and objectively resolved to further the development of improved military symbology.

A second design issue regarding TCS concerns its potential for producing a "tunnel vision" effect. The high degree of visual similarity which results from its concentric circle design may significantly degrade peripheral discriminability and thus accentuate the need for foveal eye fixation during search. An analysis of this design problem suggests that as feature similarity among members of a symbol set increases, especially among salient design features, so does the opportunity for tunnel vision.

A simple method of avoiding this effect therefore, is to:

Minimize the visual saliency of those features that must remain redundant across members of a symbol set.

4.4.3 Display Background. At present, relatively little is known about the effects of display baclground on visual search. Oddly enough, most research dealing with the perceptability of symbols has been conducted using a clear background (cf. Yoeli and Loon, 1972). A recent study by Zohar (1978), however, indicates that perceptually salient global features of the background significantly influence the user's search strategy. The display backgrounds used in Zohar's study are illustrated in Figure 4-4. Panel A illustrates a map-type background, while Panel B resembles a circuit board. The map display produced significantly better performance on a complex visual search task. This result can be attributed to the fact that horizontal and vertical lines on the circuit display are more salient than curved lines on the map display. This increased salience apparently impairs search by degrading peripheral discriminability among symbols.

The preceding example illustrates the potential impact of display background on the user's ability to search the display foreground (i.e., to perform a symbol search task). A design guide for tactical symbology displays which follows logically from the analysis is:

Minimize use of salient horizontal and vertical lines in display background.

4.5 Learnability

4.5.1 Overview. Up to this point, the range of behavioral criteria has been restricted to perceptually-based tasks. At issue in this section, by contrast, is the effect of learning on tactical symbol use. Two basic components of the learning process can be distinguished (e.g., Underwood, 1957). The first focuses on memory for a set of symbol designs (perceptual learning), while the second describes symbol-to-concept relationships

PANEL A

MAP BACKGROUND

PANEL B

CIRCUIT BOARD BACKGROUND

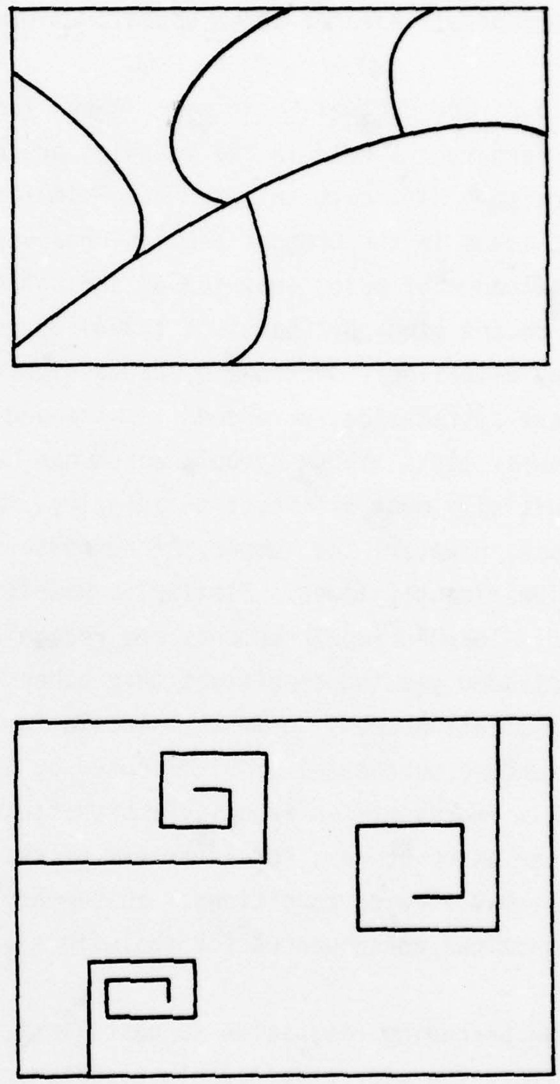


FIGURE 4-4. DISPLAY BACKGROUND STRUCTURES
[Adapted from Zohar, 1978]

(association formation). Typically, both perceptual learning and association formation occur simultaneously but, if necessary, they can be separated to independently assess the impact of symbol design on each task component. The present analysis will focus on the role of both perceptual learning and association formation in the symbol use process.

4.5.2 Perceptual Learning. It has long been known that perception plays a fundamental role in the learning process. Complex figures, for example, are more difficult to learn than simpler geometric shapes (Attneave, 1957). At issue in the present section, however, is the converse process - the influence of prior learning on the perceptual salience of symbol designs. A recent study by Shurtleff (1974) suggested that well-learned symbols may effectively overcome degraded viewing conditions. Military symbols were systematically reduced in size and used as stimuli in a recognition memory task. Those symbols which had been reduced most drastically were initially most difficult to identify. After considerable practice on the task, however, the latency of response for correct identifications was significantly lower. Similarly, Howell and Fuchs (1961) have shown that well-learned iconic symbols are recognized with fewer errors under degraded viewing conditions than other less well-known symbols. The implication seems to be that iconic familiarity can, to a certain extent, overcome perceptual problems posed by visual degradation of graphic code. This represents an especially significant finding for the tactical symbol user since he may, for a variety of reasons, be exposed to less than optimal viewing conditions. In summary, learnability has important practical consequences for the effectiveness of tactical symbology.

The preceding discussion suggests that easy-to-learn iconic symbols may afford the user considerable resistance to visual distortion. On the other hand, Hemingway, et al. (1978) have suggested that iconic symbols "create more clutter than most existing symbologies." These conflicting speculations can be examined in the context of a concrete example. Consider the symbols and overlapping configurations illustrated in Figure 4-5. It seems from the example that iconic symbols, rather than producing clutter, can perhaps assist the user in unravelling the contents of a cluttered display.

One reason for the apparent problem with conventional symbols is that they consist of simple geometric forms. When such forms are super-imposed on each other, they combine to produce complex shapes which may obscure the identity of component symbols. Iconic designs, by contrast, are complex at the outset but since they are also well-learned their features can serve as discriminative cues. It appears that complex iconic patterns may be "unitized" and stored as discrete shapes in the user's visual memory (LaBerge, 1976). A good example of unitization is the finding that words can be identified more readily than individual letters (Reicher, 1969). In an analogous way, iconic symbols may be easier to distinguish than simpler but less well-known shapes. This advantage apparently due to prior perceptual learning, may be particularly important in overcoming the problem of display clutter. Thus, the guideline that emerges is as follows:

> *To minimize distortion (especially under degraded viewing conditions), use well-learned or unitized symbol designs.*

The perceptual advantages of iconicity symbols do not necessarily extend to peripheral discriminability. An iconic silhouette drawn with thin lines, for example, may be difficult to distinguish in the peripheral visual field. If the silhouette is filled in to compensate for this deficiency, the advantages of prior perceptual learning may be diminished or even lost. However, the use of thick lines along the periphery of an outline figure may serve to improve saliency while restoring the benefits of prior unitization. This notion illustrates the complex trade-offs

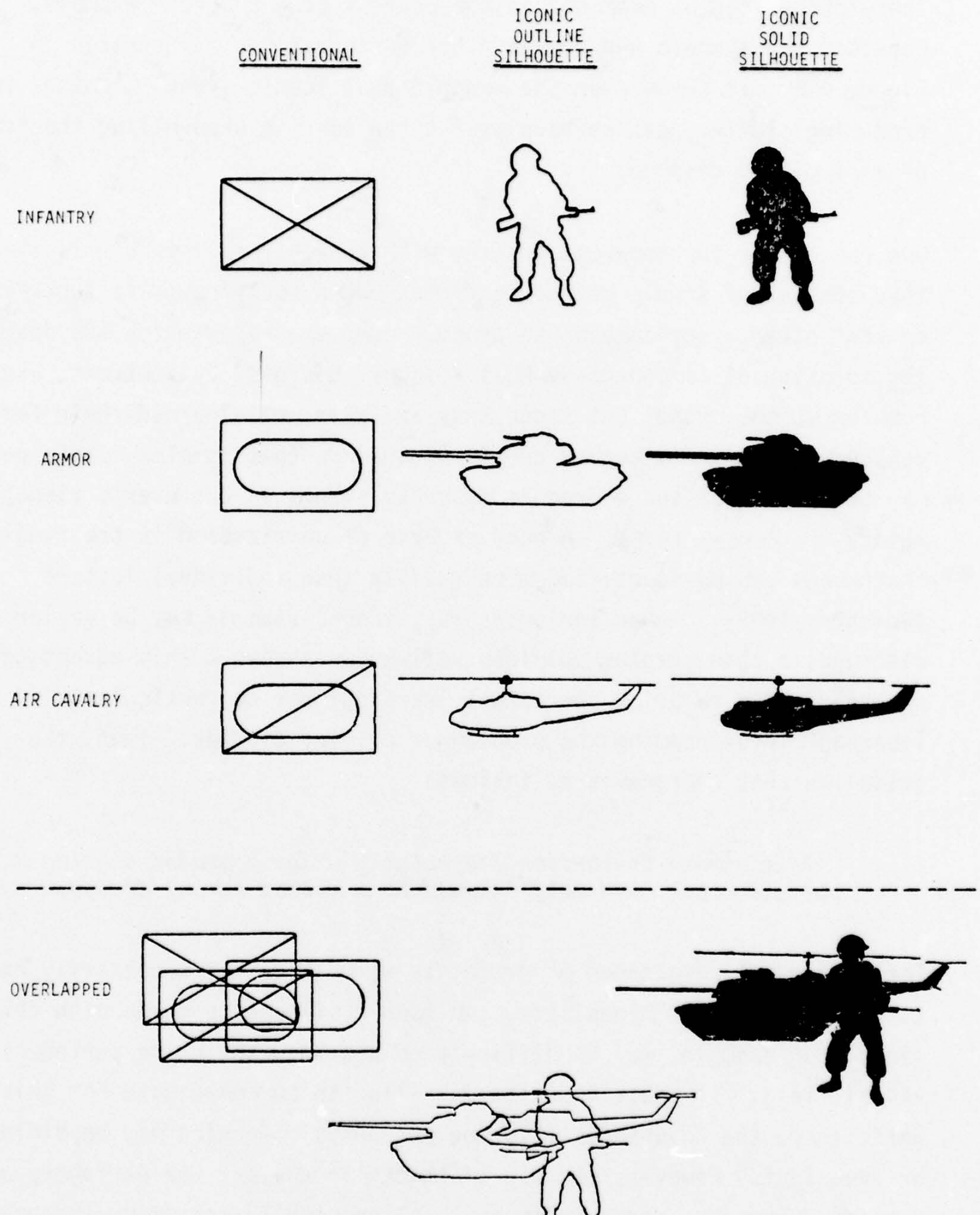


FIGURE 4-5. ILLUSTRATION OF OVERLAPPING SYMBOL CONFIGURATIONS

that can be made to optimize both learning and perception by systemmatically adjusting symbol design components.

4.5.3 Association Formation. The acquisition of a symbolic language is a two-stage process. The user must not only become familiar with the display elements for perceptual recognition; but also, the user must learn the appropriate associations between the display elements and the concepts that they are meant to portray. It is this second stage of the symbolic language-acquisition process, association formation, that is the focus of this section.

The most obvious influence on association formation is prior learning. Although there is currently no conclusive empirical support for the assumption that symbols selected for ease of association with military concepts enable the user to make decisions faster or with greater accuracy, the assumption is certainly a plausible one (Foley and Wallace, 1974; Middleton, 1977a). Also, in today's Army, there is a rapid turnover of personnel at many echelon levels which creates a situation where new personnel must continually be trained to use military symbology. Nevertheless, the symbolic language used by NATO forces (STANAG 2019) continues to be composed of symbols that have little obvious association to their referents.

One investigation of the strength of association between graphic symbology and military information was conducted by Bersh, Moses, and Maisano (1978). In this study, enlisted men were asked to rank order battlefield concepts (e.g., firepower) on the basis of their apparent association with certain sets of symbols. It was found that approximately half of the correspondencies between symbols and concepts were unambiguous. This suggests that "natural" associations can be identified. For example, color was found to be unambiguously associated with "danger." Furthermore, in another study (Levine and Mallamud, 1978), specific colors have been reliably associated (i.e., scaled) according to degrees of perceived "threat".

In a related investigation, Hemingway, et al., (1978), military personnel were asked to rank symbols on the basis of how meaningfully the symbols represent a particular military designation. Pictoral symbols were ranked higher than the current U.S. Military symbols (FM 21-30), and geometric symbols were, in turn, ranked higher than Soviet symbols. It is interesting to note that pictoral symbols, shown by Hemingway, el al., to be most conducive to association formation, constitute a form of representation that transcends language barriers such that the problem of standardization would be minimized.

In addition to rank-order methods for determining the strength of prior associations, relevant military personnel could be asked to produce their own symbols to represent concepts (c.f., Berry and Horowitz, 1961). This method has the advantage of not limiting the potential alternatives, but it raises the problem of clustering the forms obtained to permit a frequency count. Perhaps a feature analysis would render this weakness more manageable.

In an attempt to capitalize upon pre-existing associations to simplify symbology acquisition, Machover (1977) has proposed that greater effort be given to the development of real-world models, where vehicles look like real vehicles (i.e., symbols would be three dimensional). This approach, according to Machover, would possibly reduce the need for further discussion about desirable symbology. However, it would appear difficult to represent such attributes as combat effectiveness or hostility (Wheatley, 1977) in a real-world replica. Also, the emerging symbologies have a certain amount of summarization quality, whereas a real-world model would not.

From this discussion, the association-formation stage of symbolic-language acquisition can be simplified by adherence to the following guideline:

> *Take advantage of the user group's prior learning and conditioning to select symbol design features (e.g., iconicity, color) which enhance association formation. For example, if the color "red" is culturally identified with the concept of danger, it might be utilized in the portrayal of enemy threat.*

It is acknowledged, however, that this guideline cannot be followed in isolation. That is, other factors, such as display clutter, must be monitored such that ease of learning the symbology is not offset by an increased difficulty in utilizing the symbology.

Another important link that must be optimized is that between a symbol and an internalized mental representation of the symbol (i.e., a mental image). The imageability of a symbol is the ease with which an accurate mental image of its visual form can be generated. Symbols with high imageability can be located more readily in a complex display because the user can construct a veridical mental template to guide the search. Since the complexity and detail that can be generated in a mental image is sharply limited, the following guidelines for symbol design can be specified:

> *(1) Unnecessary complexity should be avoided.*
>
> *(2) Unnecessary detail should be avoided.*
>
> *(3) The Gestalt laws of Pragnanz for figural goodness (Koffka, 1935) should be followed when appropriate.*

Note that these three guidelines complement the suggestion to use iconic symbols in that the possible clutter problem with iconic symbols is acknowledged and possibly minimized.

4.6 Sample Task Analysis

Early in this chapter (Section 4.2), an informal analysis was described of a typical task requirement (i.e., *determine where the enemy is likely to conduct his breakthrough attack*); the task was decomposed into a sequence of steps involving the perceptual use of symbols and the analytical manipulation of related tactical data. Such an analysis can be undertaken at an even more detailed level with emphasis placed on perceptual-cognitive activities. Once the specific behavioral processing requirements for a given task are identified, it becomes possible to associate them with related behavioral effects which have been established in the research literature. These effects of symbol and display variables on human information processing capabilities, in turn, suggest design guidelines whose implementation might ultimately enhance performance with respect to the required symbol-use activities. To demonstrate the conceptual links between processing requirements, behavioral effects, and design guidelines, a sample task will be analyzed accordingly.

Consider, for example, a commander or intelligence officer (G2) who must *assess the functional characteristics (size, weaponry, equipment) of enemy units from a situation display*. This requirement, which might be a subtask within some more general task--e.g., *determine where the enemy is likely to conduct his breakthrough attack* (as described earlier), involves each of the key behavior components--symbol discriminability, display search, and symbol learnability (acquisition)--to some degree. More specifically, four behavioral processing steps required for task completion are listed in the left column of Table 4-1; for example,

TABLE 4-1

INFORMATION PROCESSING TASK ANALYSIS: ASSESS FUNCTIONAL CHARACTERISTICS OF ENEMY UNITS

STEP	PROCESSING REQUIREMENT	BEHAVIORAL EFFECTS	APPLICABLE DESIGN GUIDELINES
1	Access perceptual code associated with enemy/friendly graphic distinction.	Accessibility to perceptual code increases as a function of:	
		(1) Visual similarity of graphic code to tactical referent;	(a) *Take advantage of the user group's prior learning and conditioning to select symbol design features (e.g., iconicity, color) which enhance association formation.*
		(2) Visual dissimilarity of the graphic codes representing different tactical referents.	(b) *Minimize, to the extent possible, the amount of feature similarity among different members of a symbol set.* (c) *Minimize the perceptual saliency of the features that must remain redundant across members of a symbol set.* (d) *Maximize the discriminability of those graphic features used to code important tactical information.*
2	Search display for enemy unit symbols:		
	(a) visually scan display until a unit symbol is detected.	Search time to find a unit symbol increases as a function of visual similarity between symbol and background.	(a) and (b) above. *Minimize use of salient horizontal and vertical lines in display background.*
	(b) assess visual simiarity of perceptual code stored in memory (see Step 1) to perceived graphic code.	Enemy/friendly discriminability increases as the number of features common to both decreases.	(d) above.
3	Access functional concept associated with each unit symbol.	Identical to the variables specified above for Step 1.	(a), (b), (c), and (d) above.
4	Store updated functional unit characteristics in memory.	Memory encoding rate increases as memory load decreases (i.e., as the number of items encoded decreases). For example, frequent crossattachment of unit may easily exceed short-term capacity.	*Develop memory symbols, and symbols that represent important tactical indicators, to reduce the number of computational steps required in pre-decisional processing.*

Step 1 is to "access the perceptual code associated with the enemy/friendly graphic distinction." Corresponding to this process, two variables involving similarity/dissimilarity which affect accessability to perceptual codes are cited; these are listed in the center column of the table. Finally, in view of these performance effects, one or more of the design guidelines previously presented in this chapter are enumerated in the right column of the table; the guidelines selected are those that offer design principles in the direction of human-factoring the symbol/display for improved task performances. Thus, in the case of Step 1, design features (such as iconicity) are recommended which enhance association formation.

By breaking down representative tasks into step-wise information processing components, considerable insight can be gained toward defining descriptive models of the perceptual-cognitive processes involved in the use of tactical symbols. However, for the near term, this methodological approach holds much practical significance for isolating and treating potential human factors bottlenecks in the symbol-use process. Specifically, a list of required task behaviors affords the opportunity to identify those human resource limitations which may significantly impede successful task performance. By determining relevant human factors and/or display variables capable of minimizing or attenuating perceptual-cognitive load, design guidelines may be suggested which have the potential for helping to remediate task-specific information processing deficits.

4.7 Summary

The preceding analysis has uncovered a number of design features and problems associated with representatives from conventional as well as newly proposed tactical symbology (some additional examples of symbols which incorporate various design features are presentaed in Appendix E). For example, Table 4-2 provides a summary of the contrasting features of conventional symbology (FM 21-30) and potential iconic symbology. Although the comments provided in this chapter must be regarded as tentative in the absence of empirical verification, the issues raised do seem both important and readily generalizable to other symbol design candidates. A second and perhaps more important product of the preceding analysis has been the development of preliminary symbol design guidelines. The intention here was to help support future symbol design efforts by codifying, and illustrating the application of, some relationships between design variables and user-based performance criteria.

TABLE 4-2. CONTRASTING SYMBOL DESIGN CHARACTERISTICS

	CONVENTIONAL SYMBOLS (FM 21-30)	ICONIC SYMBOLS
DISCRIMINABILITY	Horizontal and vertical lines along the perimeter of each symbol (its "box") may increase confusability of unit function by increasing the similarity of salient design features. In addition, horizontal and vertical lines are especially salient and therefore compound the discriminability problem. High similarity produced by unit "box" symbols increases the potential for "tunnel vision" effects (lack of discriminability in peripheral vision). This problem becomes more serious as symbol density increases. Specific symbol characteristics: "Military Police" contains salient design features which make it more discriminable than combat maneuver symbols (such as armor); "Field Artillery" is more discriminable than most other symbols due to the salient, filled-in circle in the center; "Infantry's" diagonal lines have low salience and may produce more recognition errors than most other symbols.	Iconic symbols in general offer the user a large number of discriminative cues, and their discriminability is less affected by the visual distortion resulting from display system failures. Iconic silhouettes are easiest to discriminate in foveal vision when filled-in; outline silhouettes are not as salient in foveal vision; thick outline silhouettes produce intermediate levels of discriminability. Detailed iconic symbols decrease discriminability by increasing feature similarity among members of a symbol set.
SEARCH	Tunnel vision produced by unit "box" symbols will impair search efficiency. Lack of discriminability in the periphery accentuates the role of foveal discrimination and slows search for unit function. Because highly salient features degrade search efficiency when they are not the target of the search, high salience of unit "box" symbols may actively impair search for other symbolic codes.	Filled-in iconic silhouettes are readily discriminable in the periphery and therefore provide salient cues to direct the search process; lower salience of outline silhouettes decreases search efficiency.
LEARNABILITY	Simple geometric forms have a low association to corresponding tactical concepts -- they may not provide the resistance to visual distortion afforded by well-learned symbols.	The perception of well-learned iconic symbols is less affected by the visual system's limited acuity in both foveal and peripheral vision. The high degree of perceptual learning associated with iconic symbols can overcome to some extent the "clutter" caused when symbols spatially overlap on the display.

5. TOWARD EVALUATING THE EFFECTIVENESS OF TACTICAL SYMBOLOGY

5.1 Overview

A comprehensive methodology for evaluating the effectiveness of new symbology will require the development of:

(1) Content-based Criteria	-	standards for evaluating the functional breadth and information depth of a candidate database (Section 5.2).
(2) User-based Criteria	-	procedures for evaluating the discriminability, searchability, and learnability of proposed symbol designs (Section 5.3).
(3) Tactical Criteria	-	a set of task-based procedures for assessing the impact of alternative symbologies on tactical problem-solving and/or decision-making (Section 5.4).

The objective of this chapter is to identify representative criteria within each of these three categories and describe how each can be used to evaluate tactical symbology (an overview of evaluation considerations is illustrated in Figure 5-1). In the interests of efficiency, content-based and user-based criteria should be applied early in the development process to screen-out those symbology candidates failing to meet certain minimum standards of acceptability. The objective of this screening approach is to minimize the number of tactical simulations or field tests that have to be conducted since such tests are often both time-consuming and expensive. An even better justification, however, is that specification of explicit content and design criteria may effectively guide future development efforts.

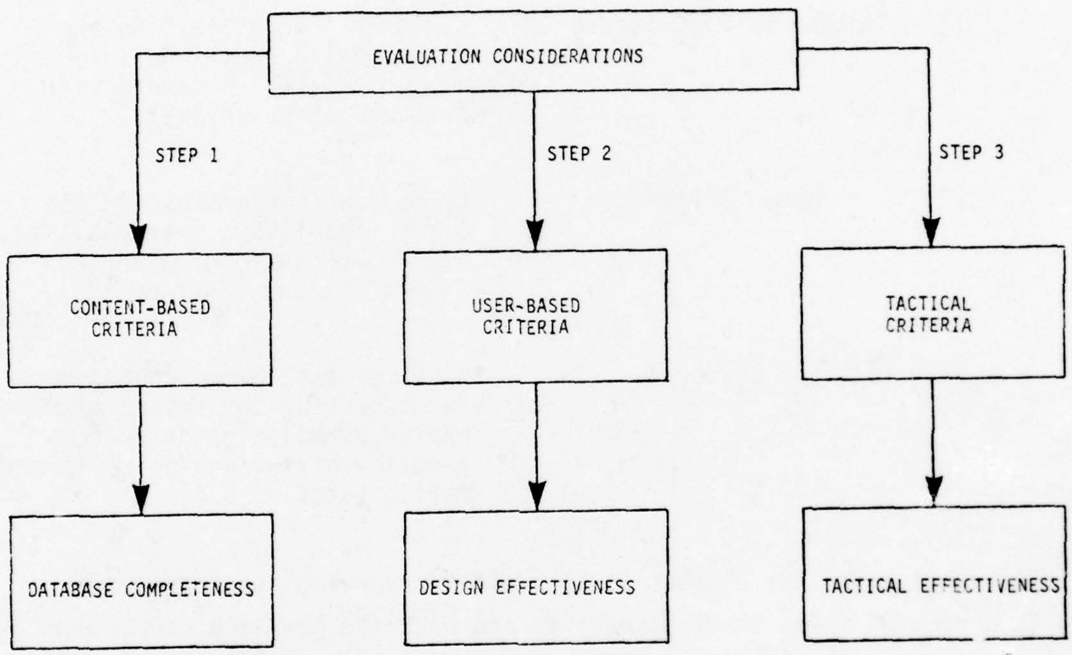


FIGURE 5-1. AN OVERVIEW OF THE EVALUATION PROCESS

5.2 Content-Based Criteria

The most fundamental requirement of improved symbology is that its database (i.e., portrayal capability) be broad enough and deep enough to offer the user a significant amount of tactical information. As described in Section 3.4.4, the breadth dimension is the number of different questions a database is designed to answer. Information depth, on the other hand, refers to the various levels of information detail at which an answer can be specified. Unfortunately, precise specifications as to what questions symbology must answer and at what level of detail have yet to be established. Chapter 3 of this report, however, identified a number of candidate data structures which could be presented to appropriate groups of military experts for review and analysis.

The goal of the review process would be to reach a concensus of expert opinion as to the content and organization of an expanded database for tactical symbology. In reviewing the proposed data structures, the experts should, at a minimum, consider such criteria as the following: (1) accuracy and comprehensiveness in view of current doctrinal requirements; (2) adaptability to future doctrinal requirements; and (3) compatibility with NATO doctrinal requirements (interoperability). An interative series of such review procedures could produce agreement as to what tactical questions new or modified symbology would have to address as well as what level of detail it should offer the user. Thus, the data structure approach to information analysis provides an objective format for discussion and serves to clarify many of the complex issues involved in defining abstract tactical concepts.

In the absence of doctrinally specified requirements, the current distinction between information breadth and depth also can be used to compare the conceptual dimensions of proposed symbol systems. Consider the sample assessment matrix illustrated in Figure 5-2. A set of illustrative tactical information concepts or categories are listed in the left-hand column. These categories operationally define the breadth-of-function dimension associated with tactical symbology. The columns of the matrix show various tactical symbologies (conventional and proposed) which can be checked against each information category. As indicated in the figure, a positive response, √, for "satisfies requirement", can be entered when the respective symbology has the capability to portray the respective information category; similarly, a ? for "uncertain" and a blank for "does not satisfy requirement" can be entered. To the extent that the information dimensions evaluated are representative of the entire set required by doctrine, this tabulation can provide a summary measure of the portrayal completeness of a symbology (dimensions can also be updated to reflect changing requirements).

Content comparisons of this type may help to narrow down the number of symbology representations by eliminating those which fail to meet even marginal standards of database adequacy. Those candidates which satisfy minimum "breadth" criteria can be subjected to further analysis using database structures to further define their content deficiencies.

5.3 User-Based Criteria

5.3.1 Overview. The impact of symbology on tactical decision making will depend on the extent to which it can be perceived and interpreted by the user. This section, therefore, describes a methodology for evaluating symbol design effectiveness in terms of user-based performance criteria. As discussed in Chapter 4, the symbol use process consists of three basic task components: (1) discrimination; (2) search; and (3) learning. The following sections will address each of these performance criteria, within an experimental and a mathematical/analytic evaluation framework.

ALTERNATIVE SYMBOLOGY

INFORMATION DIMENSION	CONVENTIONAL (FM 21-30)	MODIFIED CONVENTIONAL	COMBAT POWER (USAICS)	COMBAT CAPABILITY (A.R.I.)
UNIT SIZE	✓	✓		✓
UNIT IDENTITY	✓	✓	✓	✓
IMMEDIATE THREAT				
TYPE OF THREAT (UNIT FUNCTION)	?	?	?	?
POTENTIAL OF THREAT (UNIT CAPABILITY)				✓
PRIORITY TARGETS				
ENEMY VULNERABILITY		✓		✓
REACH OF THREAT				
SOURCE AND RELIABILITY OF DATA				
$\Sigma(\checkmark)=$	✓✓	✓✓✓	✓	✓✓✓✓

FIGURE 5-2. SAMPLE CONTENT ASSESSMENT MATRIX

5.3.2 Some Experimental Paradigms. The perceptual features of symbols can be assessed using a variety of reliable experimental procedures. Weltman and Helgesson (1972), for example, have used the visual search paradigm of Neisser (1967) to assess the legibility of commercial designs. Subjects were presented with an array of five design alternatives and a single target design. Their task was to locate the alternative which matched the target. A reaction time measure was then used to identify the most readily recognizable design. This procedure can be modified to provide a sensitive measure of the perceptual saliency associated with each tactical symbol.

Distinctiveness can also be investigated using ratings of perceptual confusability (e.g., Miller and Nicely, 1956; Sattath and Tversky, 1977). Pairs of tactical symbols could be presented to each subject with instructions to make a same/different judgment. The latency associated with each response could then be used to measure confusability. Multidimensional scaling procedures can also be applied to the resulting subject x symbol-pair matrix to identify and eliminate perceptually confusable symbols.

The ease with which symbols are learned can be assessed by pairing each one with a corresponding verbal description. When presented with a symbol, subjects can then be required to provide its correct verbal description, and conversely, when given a verbal description they can be required to select the appropriate symbol from a set of alternative targets. With this paradigm, the number of trials to reach a given criterion may be used to index symbol learnability. Once symbols have been learned, subjects may be tested for retention at various time delays. In this way, the memorability of symbols is assessed. Memorability is defined in two ways: first, learners are given a symbol and must provide its associated verbal description, and second, they are given a verbal description and must choose the correct symbol from a set of alternatives.

A second set of tasks can be designed to assess the impact of semantic factors on the perceptual distinctiveness and recognizability of the symbols. A task similar to that described previously can be used. Users who have learned symbols and associated symbol names can be given a symbol description. They would then be required to identify the correct symbol from a set of alternatives. Performance is then evaluated using a reaction time measure.

5.3.3 Mathematical/Analytical Methodology. The development of spatial frequency analysis, including Fourier Transforms, offers a potential alternative to standard experimental evaluation. A brief introduction to the spatial frequency approach and the use of Fast Fourier Transforms (FFT's) is provided in Appendix F. THe following sections will describe how a Fourier analysis might be used to assess symbol discriminability, display search, and finally, symbol learnability.

Symbol Discriminability. The Fourier technique described here for assessing symbol discriminability and/or confusability uses readily available FFT programs (e.g., Cooly-Tukey FFT algorithm). The first step is to digitize the spatial distribution of light intensity associated with each member of the symbol set and enter the digitized representation into the FFT program. There are two general methods for accomplishing this goal:

(1) Measurement of the symbol's spatial intensity distribution with a photometer and entering the measurements into the FFT via a computer terminal.

(2) Use of a TV camera of image processor with an appropriate A/D converter which automatically digitizes and enters each symbol's intensity distribution into the FFT. The digitized representations are then broken down into their Fourier

components and compared using either correlational or multidimensional scaling techniques. This provides an objective measure of symbol confusability which can be calculated selectively for either low or high frequency components to assess both peripheral as well as foveal discriminability.

The relative detectability of a symbol can also be calculated using the FFT output obtained above. The procedure is to simply use the visual sensitivity function illustrated in Appendix F as a guide to the ease with which each symbol or symbol component could be detected. Only seven bandwidths of spatial frequency are relevant to the assessment of human visual sensitivity.

Display Search. Search efficiency is known to be determined by a symbol's peripheral detectability and discriminability. Since peripheral vision is primarily sensitive to low frequency information, search efficiency can be measured by the amount of low frequency similarity among members of the symbol set. This measure of low frequency similarity can also be used to assess "tunnel vision" effects. The procedure is to sample symbol discriminability values at different levels of display density. Thus, a relative comparison of the search efficiency associated with each set of symbology to be evaluated can be obtained without collecting any human performance data.

The effects of display background on search efficiency also can be assessed using the Fourier technique. One simple procedure is to compare the spatial frequency components of all foreground information (unit symbols) with that of all background information (display structure). The resulting measure of discriminability may then be used to identify those display variables which enhance the salience of certain unit configurations (e.g., attack formations).

Symbol Learnability. A large number of standardized techniques are available for the assessment of symbol learnability (recognition memory - LaBerge, 1976; coding preference - Wheatley, 1977; symbol-to-concept association formation - Howell & Fuchs, 1961). A more interesting and perhaps more important question is the identification of those design components which facilitate learning. Since spatial frequency components correlate highly with human discrimination performance, they may have important implications for learnability as well. There is evidence, for example, to suggest that complex figures (i.e., those containing multiple orientation components) are more difficult to learn than simple shapes (Attneave, 1957).

In order to predict the rate of learning for iconic-type symbols, however, it may be necessary to obtain a somewhat different measure of symbol design. One possibility that may correlate highly with learning is the rated visual similarity of a symbol to its referent. Subjects may find it easier to "learn" symbols to the extent that they match visual codes they have previously stored in memory. This hypothesis seems consistent with the relatively low learning rates associated with abstract as compared to iconic symbology (Howell and Fuch, 1961). In any event, the development of a measure capable of predicting learnability could be exploited in future efforts to design more effective symbology. Moreover, such a measure would permit the assessment of symbol learnability without the necessity of human experimentation (e.g., spatial frequency analysis or rated similarity may serve to define learnability criteria).

5.4 Tactical Criteria

The present section provides a set of task-based performance criteria for evaluating the effectiveness of new symbology. Prior to reaching this stage in the evaluation process, it is assumed that candidate symbols have already been screened for content adequacy and design acceptability.

The objective of the present methodology, therefore, is to assess the impact of a symbology on user performance under representative tactical conditions. The most important measure of effectiveness seems to be one of processing efficiency: How accurately and at what response latency does a symbology permit the user to "answer" important tactical questions? The actual decision reached may not be nearly as revealing as the strategy of information processing adopted by the user.

To the extent that a symbology attempts to prescribe information priorities, it may also become imperative to assess the sequence in which the database is accessed. In general, it appears that a tactical evaluation scenario may be developed within the following set of methodological recommendations:

(1) The symbol system should be tested for its power as a language to present the kind of classic situations that battle staff may be expected to face.

(2) Since the battlefield is complex and will undoubtedly become more so, complex tactical situations which tax the capability of modern battlefield decision makers should be presented.

(3) An electronic display should probably be used in order to generate all of the symbol parameters and task dimensions necessary for adequate testing.

(4) Since assessment and decision-making are not made in a sterile, quiet and uninterrupted environment, a symbol system should be tested in a realistic command post environment (an environment like that in CATTS at Ft. Leavenworth would be suitable).

(5) The information requirements derived to generate the symbol system should be used as the test criteria for evaluating tactical decision making performance.

Each of these methodological recommendations can be amplified further. For example, consider the last item in the list: it calls for the selection of operational criteria (i.e., dependent measures) which are sensitive to the task performance under evaluation. By itemizing task-specific requirements (e.g., *assess threat due to recent enemy movements*), explicit, quantifiable measures of performance can be systematically defined (e.g., *accuracy and timeliness of location and/or identification of moving enemy units*). Some examples of representative tasks and corresponding performance measures are presentaed in Table 5-1. The point to be made here is that the analysis of information requirements, as discussed previously in this report, can be employed to develop a functionally-based approach to symbology assessment.

Sample Evaluation Scenario. The preceding discussions stress the importance of tactical realism and information processing complexity. One tactical problem that seems to satisfy both of these requirements is that of an active defense against overwhelming enemy strength. Modern doctrine emphasizes the importance of "counterpunching" during such an operation and this creates new information imperatives for the tactical decision maker. Essentially, the decision maker is required to locate the point of enemy penetration and determine the enemy's likely objectives. An appropriate response strategy would require an assessment of enemy vulnerability and a corresponding selection of an appropriate weapon system. Each of these tasks can and should be effectively facilitated by improved tactical symbology.

TABLE 5-1

TASK-BASED SELECTION OF PERFORMANCE MEASURES

	REPRESENTATIVE SYMBOL-USE TASK	PERFORMANCE MEASURES
(1)	Assess functional characteristics of enemy units.	Specification of the functional components of an enemy force.
(2)	Assess threat due to recent enemy movements.	Location and/or identification of moving enemy units.
(3)	Assess reach of enemy ground support.	Estimation of the distance at which enemy ground support units will no longer be effective.
(4)	Assess likelihood that enemy is aligned in combined arms attack formation.	Estimation of similarity between doctrinal attack template and current disposition of enemy units.
(5)	Assess firepower of enemy striking units.	Integration of doctrinal firing range data with current knowledge of unit size and density to produce a numeric estimate.
(6)	Identify high priority enemy targets.	Location and/or identification of enemy command, control, and communications centers.

A sample appropriate test scenario, therefore, might require the symbol user to:

(1) Find the point of enemy penetration.
(2) Determine logical enemy objectives in our rear.
(3) Structure the attack vector.
(4) Select uncommitted friendly unit.
(5) Select efficient "kill" zone in enemy sector.
(6) Determine friendly movement time to kill zone.
(7) Plot point of intersection and select unit.

This set of tasks defines an entire tactical exercise and encompasses many of the data structures presented in Exhibit 3. The objective of the scenario, therefore, would be to embed a complex sequence of tactical decision making and assessment tasks into an integrated structure which can be presented to battlefield decision makers in the context of a problem-solving/decision-making exercise.

The particular sequence of tasks listed above is highly representative of those practiced by students at the Command and General Staff College. In fact, it can be argued that collectively these tasks represent an especially challenging set of circumstances likely to confront the tactical decision maker. A scenario such as this can also serve to (a) refine the analysis of information requirements, and (b) suggest adjustments in the display system and/or modifications of symbol design. In summary, the primary advantage of a task-based evaluation is that it extends well beyond the traditional applications of symbology and assesses the impact of graphic portrayal over a wide range of tactical functions.

Sample Experiment. To illustrate a task-based methodology for evaluating the effectiveness of selected symbol design features, a sample experiment is outlined here. Assume that a preliminary analysis of alternative features may suggest that symbol iconicity with opposing orientation and vector representation (innovative design features) combined with alphanumeric annotation (a conventional design feature) may effectively facilitate the *identification of enemy breakthrough points*. An experimental test of this hypothesis requires that each task component be operationally defined in terms of one or more performance measures.

For example, consider the question of *How far can the enemy shoot into our sector?* The ability of a user to answer this question can be objectively measured by presenting a sample situation display (on paper) and instructing participants in an experiment to circle all friendly units within range of enemy firepower. Another basic subtask requires the participant to indicate where *the enemy is likely to cross the FEBA*. In this case, participants can again be given a sample situation display along with instructions to place an "X" at those points along the FEBA where they would most expect the enemy to attack. The latency or time required for each task as well as the accuracy with which each is accomplished represent objective indices of performance.

In addition to objective performance criteria, an experimental test of the effects of symbol iconicity and vector representation also requires the development of prototype symbology to illustrate the graphic concepts at issue. A sample situation display using conventional symbology is illustrated in Figure 5-3. A comparable display that combines opposing iconicity with a vectorized reach indicator is illustrated in Figure 5-4. An experimental comparison of the two displays requires a sample two-group (conventional vs. prototype) design with both groups having access to an equivalent amount of tactical information. In order to equate the groups, participants viewing the conventional display would also receive text descriptions of firepower ranges for each enemy unit; current intelligence reports on unit movement; etc.

The experimental procedure would begin by explaining and then illustrating each subtask requirement of the *breakthrough* analysis (i.e., the response measures described above). Each group would then be given a set of simulated situation displays (on paper) along with supporting text material in the standard symbology condition. Accuracy and latency measures for each task could be used to assess any performance advantages produced by the design features under investigation. For the purposes of illustration, this sample experiment combines different symbol design features into one display; however, when developing an actual experimental test plan, the independent and combined effects of separate features could be investigated and isolated through appropriate experimental designs.

5.5 Summary

This chapter has presented a three-stage approach to the evaluation of tactical symbology. The first stage attempts to insure that certain minimum content requirements are satisfied. The primary issues are conceptual rather than perceptual in nature, pertaining to the comprehensiveness, adaptability, and interoperability of a proposed database for symbology. Once these minimum standards of database adequacy have been met, the assessment of the perceptual effectiveness of candidate symbol designs can begin. There appear to be at least three psychological dimensions underlying the effective use of tactical symbols: symbol discriminability; display search; and symbology learnability (acquisition). User-based performance criteria can be developed along each of these basic dimensions. The present discussion illustrated a number of alternative approaches to design evaluation, drawing a

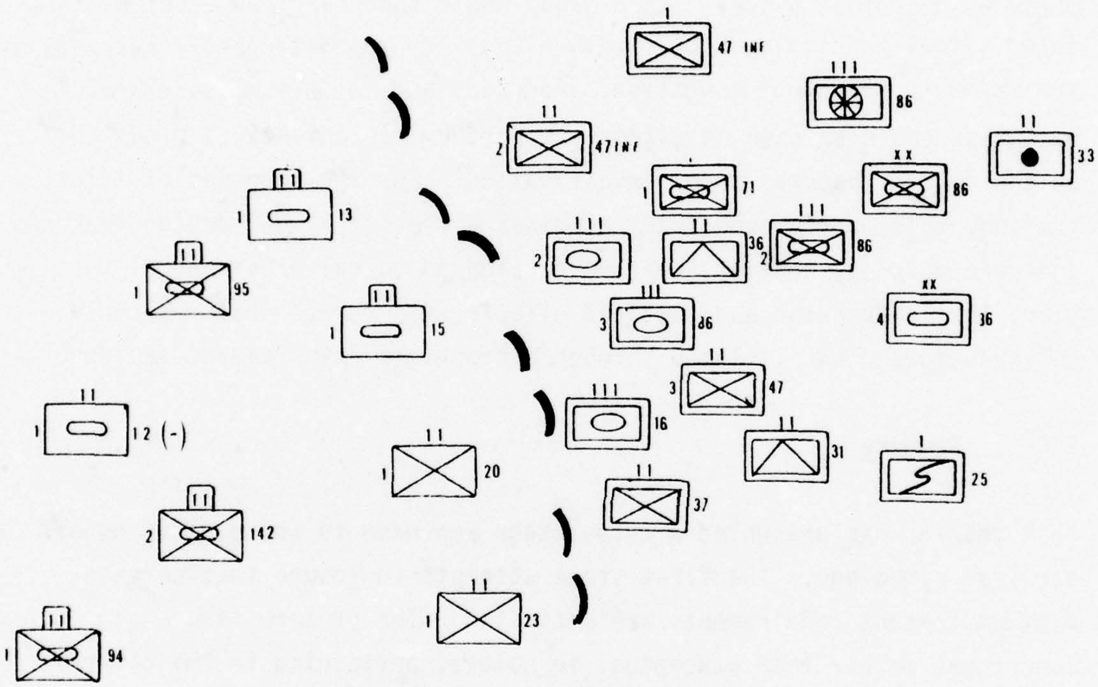


FIGURE 5-3. SAMPLE SITUATION DISPLAY: CONVENTIONAL SYMBOLOGY

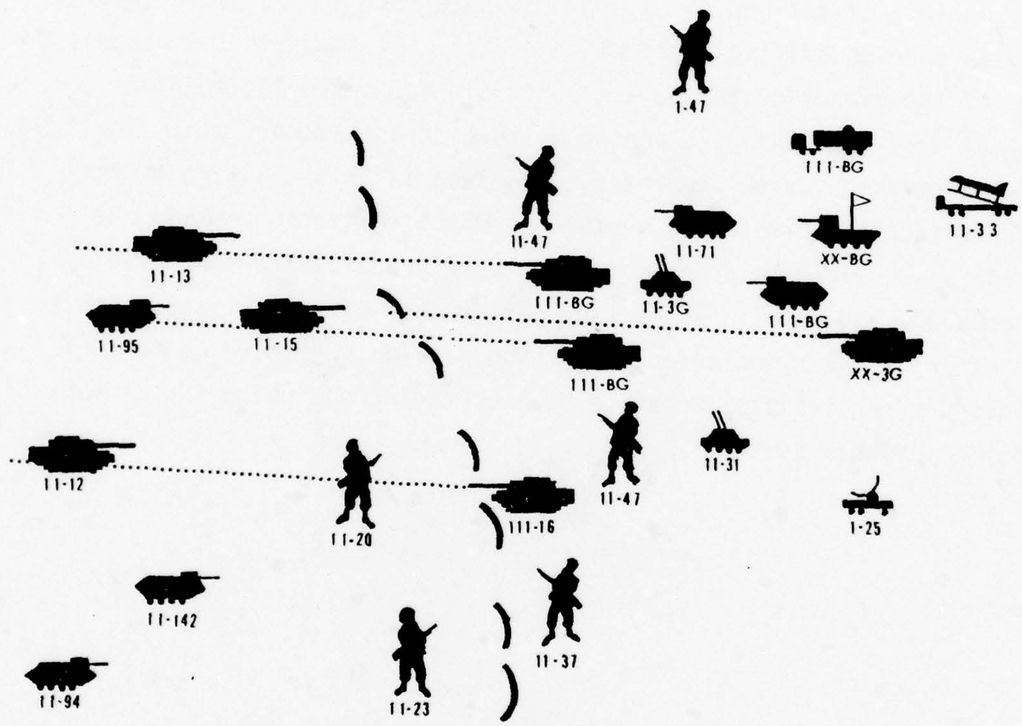


FIGURE 5-4. SAMPLE SITUATION DISPLAY: PROTOTYPE SYMBOLOGY

distinction between empirical/ experimental methods, on the the one hand, and mathematical/analytic techniques, on the other.

Finally, the third stage in the evaluation effort is designed to address the tactical effectiveness of a candidate symbol system. This stage is reached when proposed symbology is in an advanced state of development (i.e., when well-defined rules are available for mapping symbol design features onto underlying tactical concepts). At issue is the pragmatic value of the symbol system as a graphic aid for improving complex tactical decision-making, planning, situation assessment, etc. The preferred methodological approach, advocated in this chapter, is to employ a tactical simulation testbed in which realistic command and control tasks would be presented along with graphic situation displays. The accuracy and timeliness of task performance of participants working with experimental symbologies would then provide objective indices of symbology effectivensss, relative to a control group using the conventional map/symbol system.

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APPENDIX A

ADP-RELATED ISSUES

Overview

Rapid advances in automatic data processing (ADP) technology, particularly electronic display media, allow for powerful graphic capabilities that are both efficient and economic. These techniques promise to facilitate the development and implementation of sophisticated improvements for computer-displayed tactical symbology. In turn, such developments should hopefully aid command and control personnel to gain a significantly better view and understanding of the battlefield situation. However, the development of symbology for upper echelon C3 centers, requires strict adherence to the technical specifications of automated display systems. This appendix, therefore, provides a brief introduction to significant graphics display constraints as they relate to electronic picture and object representation:

(1) Effects of graphics display color and resolution on symbol clarity and variation.
(2) Display time requirements as a function of symbol population and level of detail in a displayed frame.
(3) Symbol control information - e.g., zoom parameters, colors, display status, decluttering conditions, etc.
(4) Symbol creation, manipulation, modification and retainment capabilities.
(5) Access to a symbol's associated information.
(6) Symbol transmission via graphics exchange communication protocols.

Color and Resolution

Color graphics display systems commonly generate separate red, green, and blue (RGB) video signals which can combinatorily produce the following colors on a color monitor: white, green, yellow, cyan, magenta, red, blue, and black. Generally, resolution is 512 x 512 rasters and the monitor is refreshed at 30 times per second. The availability of eight colors provides good flexibility in designing meaningful tactical symbols. However, a standard paper map symbol can be represented by a greater number of incremental changes than its electronically displayed counterpart. Certain geometrical shapes--e.g., curvi-linear shaded areas and symbols composed of curved lines, are not easily displayed in 512 x 512 space. Thus, the resolution constraint requires greater investigation and experimentation to find appropriate symbol representations.

Display Time

Acceptable display generation time is a function of the symbol population and level of detail displayed in a frame. Display time ranges from "real-time" for simple symbols with some detail overlaying a projected or already displayed topographic map, to "slow-time" for displays dense with symbols and detail. Slow-time may be from 3 to 10 seconds, depending on symbol complexity and data base access time. A critical factor of course is the time required to display complete topographic data from a digital data base--e.g., vegetation, hydrography, man-made objects, etc. Display time could be as much as 5 minutes or more to produce a highly detailed frame. One feasible alternative to a complete digital data base is the integration of a video-disk, containing randomly accessible map frames, with a digital symbology data base. Both would be controlled by interaction with a computer-based symbology management system. Map frames could be quickly accessed from a video-disk and the output mixed with the computer-generated symbology corresponding to the referenced map area; the total data configuration would then be displayed on a monitor.

Symbol Control

In contrast to historical information which maintains a static existence in the database, control information such as symbol type, zoom parameters, colors, display status, location, decluttering conditions, etc., are dynamic entities related primarily to the display lifetime of the symbol unless a frame is saved for later viewing. High speed computation and analysis of these "atomic" items are required to rapidly generate and manipulate a display with a number of independent symbols. The control-information requirements for a symbology are very complex and difficult to design into an efficient digital representation.

Symbol Operability

The capability for the creation (definition), manipulation, modification, and retainment of symbols should be embodied in powerful yet easy-to-use procedures. Such procedures should be an integral part of the graphics system software. The higher the level of the graphics language, the higher the potential degree of symbol operability.

Associated Information

Symbols not only consist of geometrical properties, but usually have other information associated with them--e.g., name, location, components, condition. This information should be readily available in the database and dynamically accessible when varying levels of detail are requested. This requires an overall structure or "template" that is consistent across symbols in order to allow rapid access, manipulation and modification.

Symbol Transmission

Graphics exchange/communication protocols require evaluation for their impact on the design of tactical symbols and their historical information and control structures. Transmission of symbol information should be independent of any hardware that processes it or any terminal that will display it. Symbol design must adhere to "information packet" specifications that will carry the symbol from one location to another. For instance, the Network Graphic Group, a working group of ARPA Network Members, has, with considerable thought and hard work, developed a Network Graphics Protocol covering graphics standards and graphics communication.

APPENDIX B

DEFENSIVE SCENARIO
EUROPEAN SETTING

STRATEGIC SCENARIO

Strategic Environment

The reality of deployed NATO and Warsaw Pact forces in Northern and Central Europe inexorably poses the threat of tension and crisis escalating to war. Both the United States and the Soviet Union have vital national security interests in Europe that are dramatically reflected in their military contributions in the two opposing alliances. Combined with military forces of other alliance/pact members, the European theater is composed of large, modern, and potentially destructive forces unparalleled in the history of warfare.

NORTHERN AND CENTRAL EUROPE	NATO	WARSAW PACT
Combat and direct support troops available	625,000	895,000
Tanks	7,000	19,000
Tactical aircraft	2,050	4,025
Nuclear weapons	7,000	3,500

Strategic Developments

It is now 6 August 1979. Amid a background of steadily deteriorating relations between NATO and the Communist powers and increasing global tension, ministers of the Warsaw Pact nations meet with the Politburo and agree to attack West Germany. East Germany, Poland, and Czechoslovakia are most receptive, and their forces are called on to participate in the offensive. Hungary, Bulgaria, and Romania will move forces to the borders of the southern NATO countries to prevent NATO from reinforcing central Europe. Covert preparations are initiated, to include the assembly of rolling stock and increasing units to full strength.

Subsequent chronological events leading to hostilities are:

(1) On 8 August, Warsaw Pact nations initiate full mobilization. Pact nations make every effort to limit NATO intelligence operations and thus hope to complete substantial military preparations without permitting a firm indication of their intent.

(2) On 9 August, Moscow publicly announces a forthcoming field exercise to test Warsaw Pact defense plans, and at the same time a restriction on foreign travel within Warsaw Pact countries is invoked.

(3) On 10 August, Intelligence reports indicate that Soviet military traffic from western USSR to Poland and East Germany is unusually heavy and appears excessive to the needs of the previously announced field exercise. Supreme Allied Commander Europe (SACEUR) orders a state of Military Vigilance.

(4) By 11 August, the Warsaw Pact buildup in Communist Europe is apparent to the West. Increased rail, road, and air activities, as well as the arrival of several Soviet divisions in East Germany have been confirmed. SACEUR requests authority to declare Simple Alert.

   (a) The request is transmitted to the NATO Secretary General, who chairs the Defense Planning Committee (DPC). This committee consists of the permanent representatives to the NATO council, with the exception of France and Greece, and is vested with authority over the major NATO commanders (SACEUR, SACLANT, and CINCHAN).

After consulting with their national governments as well as their permanent representatives to the NATO Military Committee, the permanent representatives to the DPC voice no objection to SACEUR's request when polled by the Secretary General, who then authorizes the declaration of Simple Alert.

(b) As a result, SACEUR alerts his allied force headquarters in northern, central, and southern Europe. Headquarters, Allied Forces Central Europe (AFCENT), in turn, places its two Army groups and Headquarters, Allied Air Forces Central Europe (AAFCE), along with its two Allied Tactical Air Forces (ATAF's) on increased alert.

(5) On 13 August, because of the increased pace of the Warsaw Pact buildup, SACEUR issues planning guidance and requests authority to declare Reinforced Alert. The DPC, now in continuous session, approves the request. Efforts by the UN to halt the Warsaw Pact buildup continue to be unsuccessful. CINCENT issues theater guidance.

(6) On 14 August, evidence is received that Warsaw Pact forces are mobilizing and will soon attack. As a result, SACEUR receives authorization from the DPC to declare General Alert. NATO forces begin moving to their assigned emergency defense positions. Obstacle construction is initiated. The U.S. Congress declares a state of national emergency and orders units and members of the Ready Reserve and Standby Reserve to active duty. The President orders the deployment of dual-based forces to Europe. Other NATO nations commence mobilization at the same time.

(7) On 15 August, an increase in tactical air movement is detected - generally to bases in the vicinity of known training areas in the German Democratic Republic (GDR).

(8) On 16 August, Soviet forces continue to deploy into East Germany and Czechoslovakia.

(9) By 18 August, a major portion of the Soviet theater reserve forces has arrived in western Poland and are deployed along lines of communication that would facilitate their rapid movement into East Germany.

(10) On 20 August, Pact units are detected moving toward the western borders of East Germany and Czechoslovakia. NATO units patrolling border areas report the evacuation of civilians and other noncombatants.

(11) On 21 August at 0320, enemy units are detected 1-2 KM from the international border along much of the sector assigned to the 10th (U.S.) Corps (a sketch of CENTAG dispositions and an enemy situation map are attached). At 0330, heavy artillery and mortar fire is received by several elements of the 10th (U.S.) Corps positioned near the international border. At 0345, a BN size reconnaissance force is seen moving across the border at coordinates NB 6730 (see Enemy Situation Map).

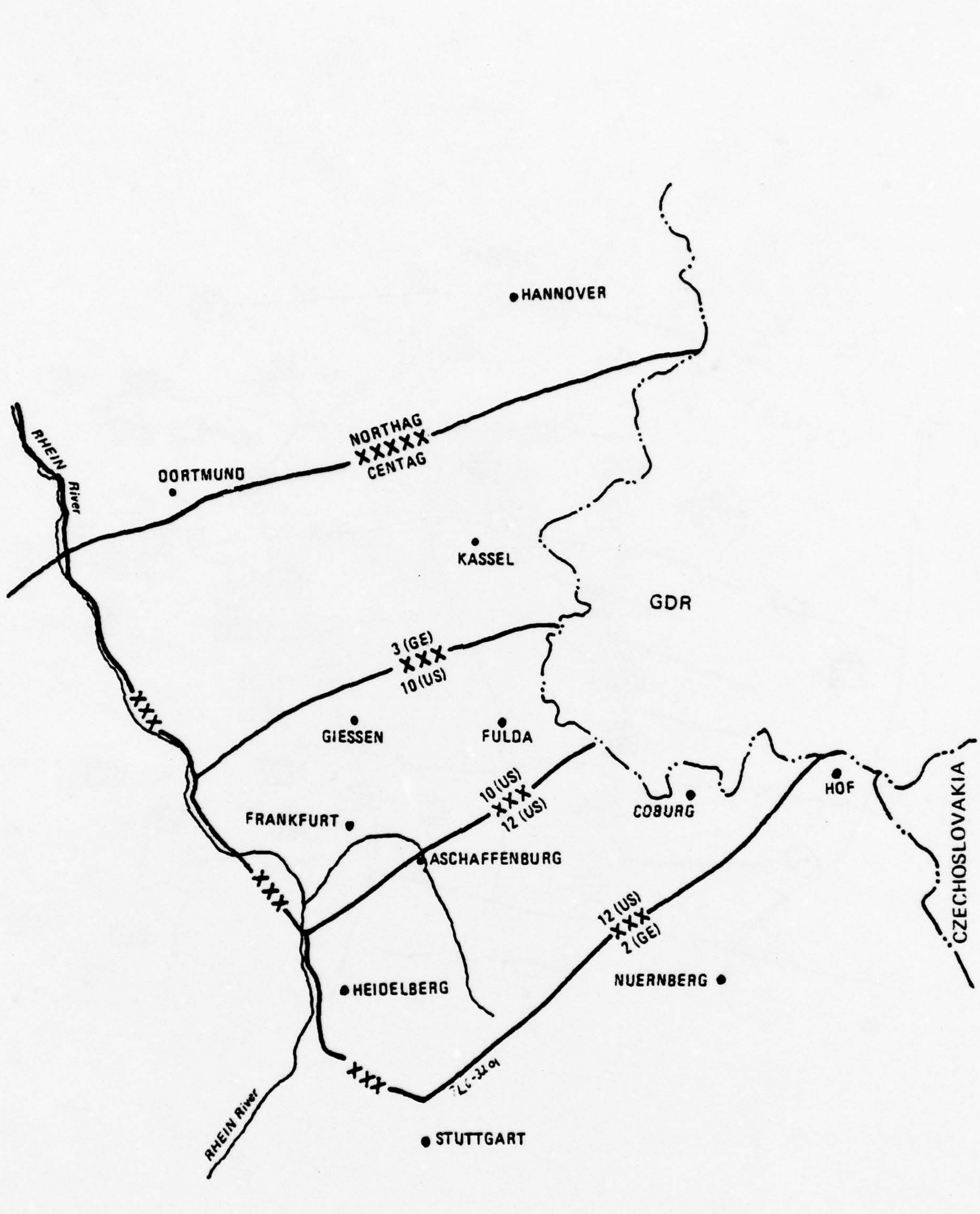

FIGURE B-1. SKETCH OF CENTAG DISPOSITIONS

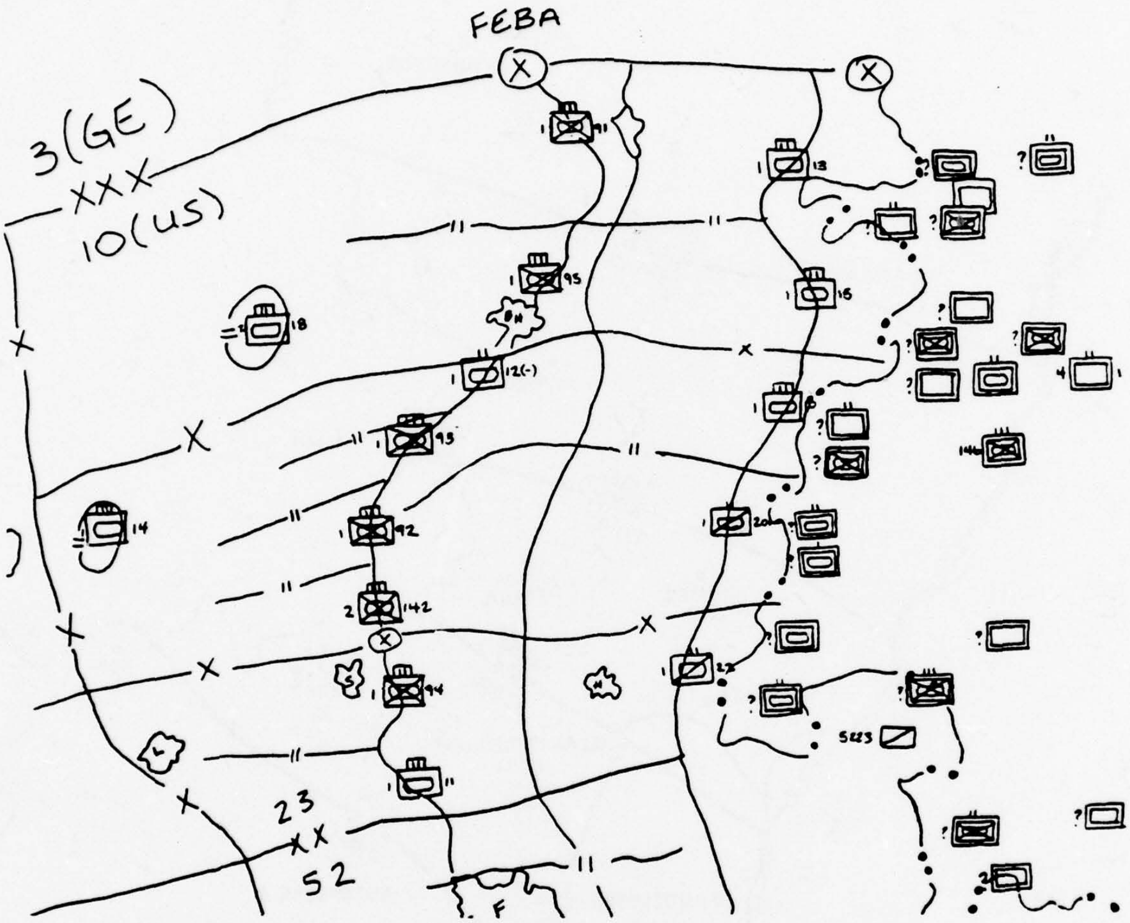

FIGURE B-2. SITUATION OVERLAY

MISSION: DEFENSE OF SECTOR FROM NB486505 TO NB425120

Comparison of Forces

Friendly Force:

The 23d Armored Division will be operating as part of the 10th Corps in the assigned sector as depicted on the situation display. The division is at full strength, their task organization is given in Table B-1. All TOE equipment has been issued, no major equipment shortage exists. Troops have been undergoing intensive combat training. Moral is good.

Enemy Force:

The forces opposing the 23d Division are elements of the enemy First Zapadnian Front. The front is composed of a shock army, two combined arms armies, and two tank armies. This front consists of approximately 11 motorized rifle divisions and 12 tank divisions. When the enemy attack, it is estimated that nine of these divisions (3 motorized rifle and 6 tank) will be employed against the 10th Corps. The first echelon will consist of 3 motorized rifle and 2 tank divisions, with 4 tank divisions in the second echelon (see Table B-2).

As normal, the front has an additional Army, presently being mobilized, that could be employed in the U.S. sector.

As part of the enemy's strategic reserve, up to 5 airborne divisions could be employed by the central front against the 10th Corps sector.

TABLE B-1. TASK ORGANIZATION: 23d ARMORED DIVISION

1ST BRIGADE

1-91 Mech
1-95 Mech
1-13 Armor
1-15 Armor
TF 2-18 Armor (2T, 1M)
1-50 FA (DS)
1/A/440 ADA (atchd for CFA opn)
1/B/23d CEWI
  (6 GSR Tm, 3 REMS Tm)
1 IPW Tm/23d CEWI
1 OPSEC Tm/23d CEWI
A/23d Engr (+) (DS)
  A/510th Engr Cbt Bn (Corps) (+) (OPCON)

2D BRIGADE

1-92 Mech
1-93 Mech
1-10 Armor
1-12 Armor(-)
1-14 Armor
1-201 Armd Cav Regt
  1/5021 Engr Co
TF 2-142 Mech (2M, 1T)
B/1-11 Armor
1-51 FA (DS)
2/A/440 ADA (atch for CFA opn)
2/B/23d CEWI
  (9 GSR Tm, 4 REMS Tm)
1 IPW Tm/23d CEWI
1 OPSEC Tm/23d CEWI
Task Force 510 Engr (DS)
  510th Engr Cbt Bn (Corps) (-)
B/23d Engr (OPCON)
D/23d Engr (OPCON)

3D BRIGADE

1-94 Mech
1-11 Armor (-)
1-22 Cav
B/1-12 Armor
1-52 FA (DS)
3/A/440 ADA (atchd for CFA opn)
3/B/23d CEWI
  (3 GSR Tm, 3 REMS Tm)
1 IPW Tm/23d CEWI
1 OPSEC Tm/23d CEWI
C/23 Engr (-) (DS)
C/510 Engr (-) (OPCON)

TABLE B-2. FIRST ZAPADNIAN FRONT

CODE NAME ORO
CODE NUMBER 351568
AREA OF OPERATIONS Central Europe

UNIT	COMMANDER	CODE NO.
CG.	Marshal DZIEDZIC	
CofS.		
H&S Bn.		
12th Shock Army		339994
2d CAA.	Gen Col PESTEL	200711
8th Gds Tk Army	Gen Col MURAVIEV, O	439276
5th Gds Tk Army		505722
20th CAA.		
35th SSM Bde.	Gen Maj BIBIKOV, G.	528620
31st Engr Const Regt.	Col KUTUZOV, J.	
19th Engr Pon Regt.		
44th Sig Regt		
129th Med Regt.		
Cml Bde		
EW Bn		
Sig Intep Regt.		
Intel Regt.		
2d Arty Div		
4th MT Bn		
18th Engr Pipelaying Bde.		

APPENDIX C

ELICITATION DATA

PARTICIPANT: G-2 (INTELLIGENCE)

PROMPT 1: UNDERSTAND THE ENEMY

Which are the combat units?

Which type of combat units?

What is their composition?

What is their special weapon capability?

What is their percent of combat effectiveness?

What is principal area of deficiency?

To what degree is this area depleated?

What vulnerability is afforded by the terrain?

What vulnerability is afforded by visability?

What vulnerability is afforded by lack of mobility?

What vulnerability is afforded by lack of firepower?

PROMPT 2: SEE THE BATTLEFIELD

What units are moving towards us?

What units are moving fastest toward us?

What units are closest to us now?

What kind of threat must we respond to?

What is the range of enemy striking units?

Will terrain limitations alter range for weapons platform?

Will POL limitations alter range for weapons platform?

What is added range of weapon itself?

What is the source of information?

How reliable is the information?

How accurate is the information?

Is there an increase in activity?

Is there movement into attack formation?

What area does the smoke prescribe?

In which direction is it moving?

How long will it remain?

PROMPT 3: CONCENTRATE AT THE CRITICAL TIMES AND PLACES

Where are the enemy's tactical nerve centers?

Where is the heart of the target?

What is the area of the target?

What is orientation of mass of enemy units reported moving across FEBA?

What logical avenues of approach are available in that direction?

Where are lead attack regiments going to intersect the avenue of approach?

Where in our rear has he prepositioned a raid?

What is the primary objective?

What route will he take?

What is the range of intervisability?

Is the terrain undulating to obscure the target part of the time?

Which are the strike aircraft?

What is their target category?

What is their target speed?

What is the primary friendly counter weapon?

PROMPT 4: FIGHT AS A COMBINED ARMS TEAM

What type of air support is available?

How much time is remaining on station?

What type of attack capability is present?

How many sortees are available?

What is the percent of our unit readiness?

What type of mobility do we have?

What angle of attack shall we use?

What is the direction of response?

How much distance is to be traveled?

What is the elapsed time estimated for closure?

What is the area of operation boundaries for our autonomous tank killer teams?

Where are the present locations and status of the teams?

What is the resistance status of the teams?

Where are the enemy air defense units?
What is the range fan of the AD units?
Do the ranges overlap?
What is the least risky path through the overlap to our objective?

PROMPT 5: EXPLOIT THE ADVANTAGES OF THE DEFENDER

What percent of our units are in their forecast defense positions?
What percent of our units have improved their positions and dressed them with fresh camouflage?
What percent of our units have operations and patrols out and active?
How can we tell when our units are mutually supporting?
What degree of combined arms status have they achieved?
What is the fire relationship between/among units?

PARTICIPANT: G-3 (OPERATIONS)

PROMPT 1: UNDERSTAND THE ENEMY

Where are the combat units?

What type of combat units are they?

Have any of the units been augmented with special troops?

Has the augmentation changed the enemy mobility or expertise?

Do the combat units have any special weapons?

Are the enemy units unique combinations of combined arms forces?

Is the enemy vulverable due to a lack of mobility?

Is the enemy vulnerable due to a lack of firepower?

PROMPT 2: SEE THE BATTLEFIELD

Which enemy units are moving?

In which direction and how fast are they moving?

Are the units moving into an attack formation?

Can enemy artillery hit any of our units?

Is there smoke obscuring parts of the battlefield? If so, where and how long is it expected to last?

PROMPT 3: CONCENTRATE AT THE CRITICAL TIME AND PLACES

Where are the regimental and higher echelon command and control centers?

How much area do these centers occupy?

Where is the enemy going to cross the FEBA?

Which avenues of approach will the enemy take?

PROMPT 4: FIGHT AS A COMBINED ARMS TEAM

What is the degree of our unit readiness?

What type of mobility is available?

Is there air support available? If so, what type?

How long will the air support be available?

How far do our units have to travel to contact the enemy?

What is the estimated time of closure?

PROMPT 5: EXPLOIT THE ADVANTAGES OF THE DEFENDER

What type of defensive positions have our units established?

Are the units camouflaged?

Where on the battlefield can we place obstacles?

What types of obstacles are available?

Are the obstacles in place, under construction or pending delivery?

What is the expected delay factor created by the obstacles?

Is there coordinated fire between and among our units?

APPENDIX D

A BEHAVIORAL REQUIREMENTS TAXONOMY FOR SYMBOL USE

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Overview

This taxonomy, which was derived from an inductive analysis of a variety of literature sources, assumes that in order to use tactical symbols, the user must first acquire knowledge about them, and then interact with them behaviorally at the level of a single symbol, or at the level of a collection or pattern of symbols.

A. Symbol Acquisition

The acquisition of a symbolic language is a two-stage task. First, the user must learn the stimulus elements (perceptual learning), and then the user must learn the appropriate associations between the stimulus elements and the concepts that they are said to portray. Thus, the acquisition of a symbolic language is a task of paired-associate learning (Greeno, 1970).

(1) Perceptual Learning - the acquisition of a code necessary for future recognition of a form.

(2) Association - the acquisition of a mental link between a form and the concept that it portrays.

B. Processing Individual Symbols

The utilization of individual symbols is also, in general, a two-stage process. A symbol must be detected and then it must be identified. However, tracking (sustained detection) and updating (re-identification) are additional behaviors that are common in processing symbols in a tactical display.

(1) Detection - the acknowledgment of the presence of a form or class of forms.

(2) Identification - the interpretation of a detected form.

(3) Tracking - the sustained detection of a mobile form.

(4) Updating - the acknowledgment of an alteration of a form.

C. Processing Multiple Symbols

In processing multiple symbols, the user could be searching for differences or similarities among the symbols. In the case of searching for similarities, the most common form of summarization is counting. These proceses, discrimination and counting, are said to follow the detection and identification of individual symbols. In addition, for the skilled user, meaningful spatial patterns of the symbols could probably be identified in much the same way that a chess master interprets the configuration of the pieces on a chessboard.

(1) Discrimination - the acknowledgment of differences among two or more identified forms.

(2) Counting - keeping track of the number of instances of a given form class encountered.

(3) Spatial Pattern Recognition - the interpretation of the spatial arrangement of two or more identified forms.

APPENDIX E

SOME SYMBOL DESIGN CANDIDATES

INTRODUCTION

On the pages to follow, examples of some proposed symbol design candidates are provided. For each symbology represented, a brief description of its rationale and design features is given followed by illustrative drawings of some sample symbols.

MODIFIED CONVENTIONAL SYMBOLOGY

A slight modification of conventional symbology will permit the graphic portrayal of combat effectiveness (Middleton, 1977a). Proportional shading within the double box can be used to reflect any desired percent level of combat strength. This symbology has the advantage of displaying the unit effectiveness dimension without requiring retraining on the part of the user.

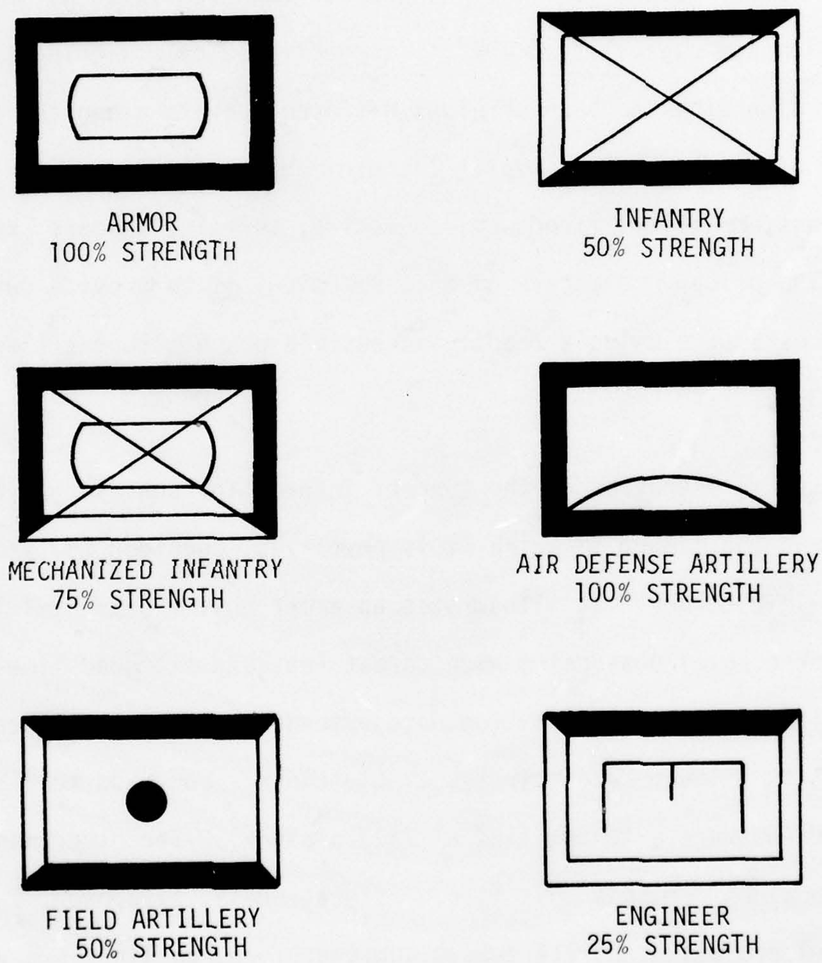


FIGURE E-1. MODIFIED CONVENTIONAL SYMBOLOGY

TACTICAL CAPABILITY SYMBOLOGY (TCS)

TCS was developed by Dr. Raymond C. Sidorsky at the U.S. Army Research Institute (ARI) as a supplement to conventional unit symbology (Sidorsky, 1977). TCS allows for the graphic representation of both unit function and capability. This is accomplished by assigning specific capability dimensions to each of eight different points along the circumference of a circular unit symbol. These dimensions include: threat, effectiveness, mobility, firepower, logistics, terrain, support and density. The primary objective of this symbology is to provide current capability estimates using a readily accessible graphic format (See Section 2.3.1).

As an illustration of the type of information conveyed by this symbology and the manner in which it is portrayed, consider the sample in the top-left corner. It illustrates an armor unit (horizontal line within inner circle) possessing high threat (outward extended line at 12 o'clock), excellent mobility (outward extended line at 3 o'clock), poor logistics (line between circles at 6 o'clock), and good terrain positioning (outward extended line at 7:30 o'clock). The other capability dimensions for this unit (i.e., effectiveness, firepower, support, and density) are all at normal levels and therefore, no lines are indicated at their respective clock positions.

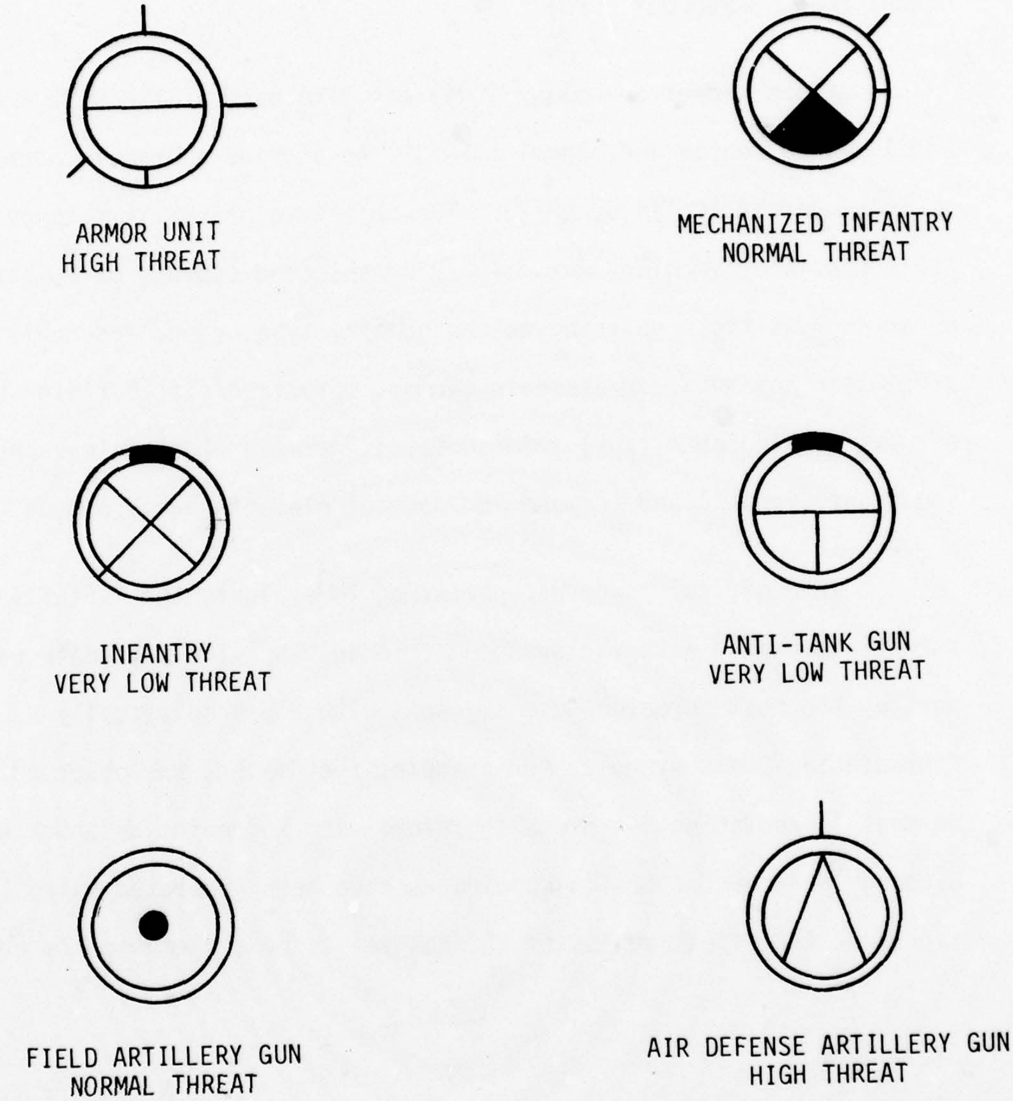


FIGURE E-2. TACTICAL CAPABILITY SYMBOLOGY (TCS)

COMBAT POWER SYMBOLOGY (CPS)

Combat Power Symbology (CPS) was developed at the U.S. Army Intelligence Center and School (USAICS) to provide a graphic portrayal of enemy threat (Colanto, 1977). The objective of CPS is to provide an ADP compatible symbology for displaying selected aspects of combat power such as those relating to the number, type, range and mobility of certain key maneuver elements (armor, motorized rifle, field artillery, air defense and anti-tank). In addition, certain electronic support equipment (radars) and command and control elements are depicted.

An empirical study was performed to evaluate the "intuitive" threat associated with various geometric shapes. The rationale was to portray the most threatening enemy unit with a psychologically "threatening" unit symbol. For example, the diamond was observed to be most "threatening," and was therefore used to depict an armor unit. Although a number of design candidates have been generated using this approach, the effectiveness of CPS has yet to be systematically evaluated.

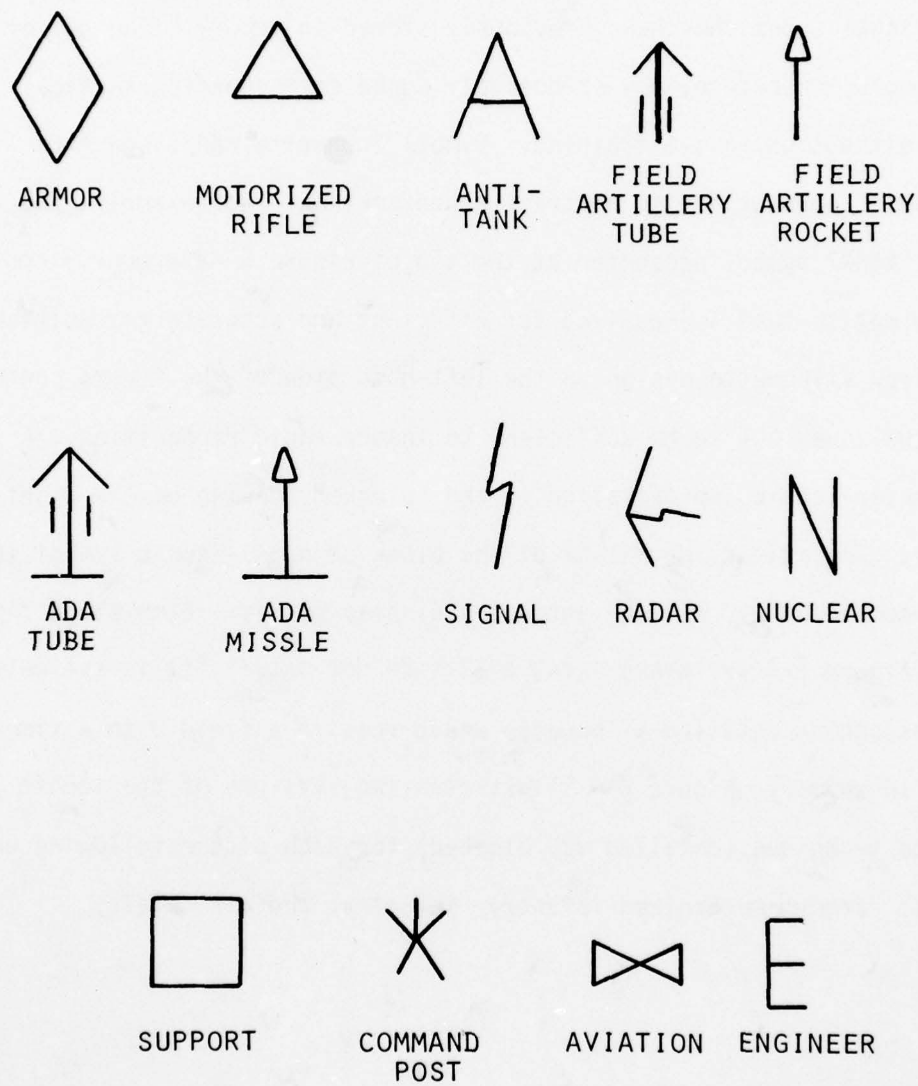
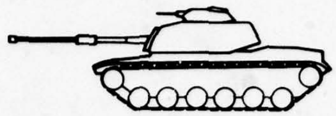


FIGURE E-3. COMBAT POWER SYMBOLOGY (CPS)

ICONIC SYMBOLOGY

Military personnel may find it relatively easy to learn symbols which "match" visual codes they have previously stored in memory. The use of iconic images, therefore, may effectively evoke corresponding tactical concepts without extensive training. Symbol iconicity can range from photographic reproduction to abstract approximation. For example, the detailed "tank" symbol presented at the top of Figure E-4a probably contains more information than is required for efficient and accurate recognition. The detailed silhouette design on the left-hand side of the figure contains fewer visual cues but seems sufficient to insure rapid recognition. An event simpler iconic approximation is the "blocked" design on the right-hand side. The primary advantage of the block or quasi-iconic symbol is its relative compatibility with an automated display system. Each block figure shown in Figure E-4 was drawn using a 12 X 28 dot matrix (it is estimated that the corresponding detailed silhouette would require a field 3 to 4 times as large). In summary, Figure E-4 illustrates two versions of the iconic silhouette technique (detailed vs. blocked) for each of the following unit functions: armor; mechanized infantry; infantry; and air cavalry.

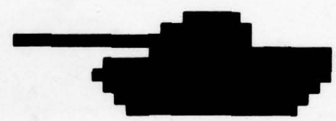


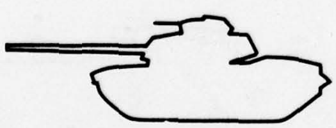
ICONIC IMAGE

DETAILED SILHOUETTE

BLOCKED SILHOUETTE

(FILLED)





(OUTLINE)

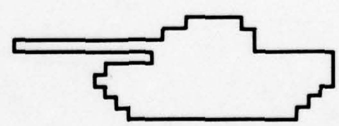
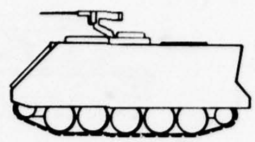


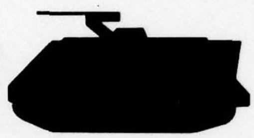
FIGURE E-4a. ICONIC SYMBOLS: ARMOR



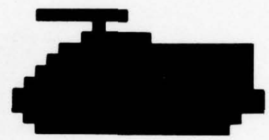
ICONIC IMAGE

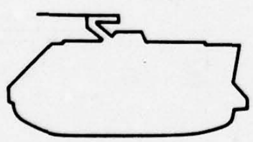
DETAILED SILHOUETTE

BLOCKED SILHOUETTE



(FILLED)





(OUTLINE)

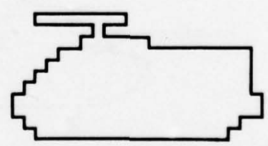


FIGURE E-4b. ICONIC SYMBOLS: MECHANIZED INFANTRY

ICONIC IMAGE

DETAILED SILHOUETTE

BLOCKED SILHOUETTE

(FILLED)

(OUTLINE)

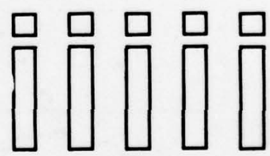
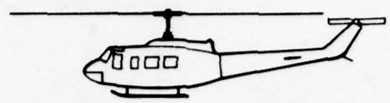


FIGURE E-4c. ICONIC SYMBOLS: INFANTRY

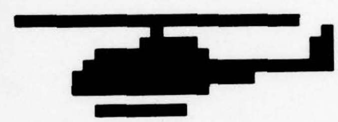


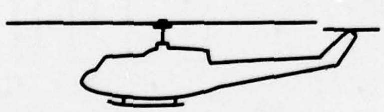
ICONIC IMAGE

DETAILED SILHOUETTE

BLOCKED SILHOUETTE

(FILLED)





(OUTLINE)

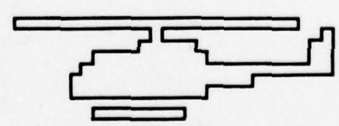


FIGURE E-4d. ICONIC SYMBOLS: AIR CAVALRY

APPENDIX F

SPATIAL FREQUENCY ANALYSIS

Overview

The objective of this appendix is to describe a newly-developed cost effective technique which may prove useful in integrating a number of seemingly inconsistent empirical research results and may provide a sound basis for future symbol design efforts. This technique--known as Fourier analysis--represents a convenient mathematical structure for simplifying complex wave patterns such as the visual information contained in a tactical symbol design. The problem addressed by the procedure becomes evident from the following quote:

> *"One might present subjects with visual displays consisting of every shape, intensity, size, etc., that one can think of, and catalog the resulting judgments of brightness. However, since there is no limit to the number of shapes ... that one can invent, the research and the catalog would never be completed. Obviously, it is necessary, instead, to try to find some relatively small set of relationships among the relevant variables... that will predict accurately the results of any possible experiment."* (Cornsweet, 1970)

Toward alleviating this problem, the Fourier approach does in fact seek to identify and analyze such relationships.

Fourier Analysis of Two-Dimensional Shapes. When an orchestra plays a chord, the sound that is created can be analyzed or broken down into its component tones. In an analogous way, a visual scene can be broken down into its components. The method that is used to do this is Fourier analysis, which is a mathematical process that can be closely approximated by computer programs known as Fast Fourier Transforms, or FFTs.

Once a scene has been broken down into its components, it can be manipulated. In particular, the transformed representation can be filtered, and a visual scene reconstructed with some of its components missing. A recent application of this technique has been developed by Arthur Ginsburg at Wright-Patterson, A.F.B. Briefly, he performed a digital conversion on the photograph of a woman's face and entered the data into an FFT program. After the transform was completed, the result was a digitized representation of the components of the portrait. These components were then filtered into seven different channels. The first channel contained only the lowest frequency information, the second the very low frequency information, the third low, the fourth middle, the fifth high, the sixth very high, and the seventh highest. These seven transformed, filtered representations were themselves entered into the FFT program to reconstruct their corresponding visual images. The results were seven versions of the original portrait, each containing only a limited amount of the original information. It can be seen from the seven versions that:

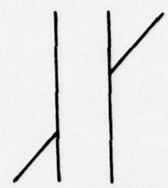
(1) Very low frequency information is about the form of the object; the shape of the head and placement of eyes, nose, and mouth. The portrait is recognizable as "a face".

(2) Low frequency information is sufficient to identify the face. A person acquainted with the subject of the portrait would recognize her in this version.

(3) Higher frequency information is about details. Texture and finally edges are represented. This information is not necessary for recognition of the face, although it might show details important for some other purpose.

In creating each of the seven versions, filters of two-octave bandwidth were used. Filters narrower than this do not produce versions of the portrait that are useful to the human visual system.

A further demonstration by Ginsburg shows the power of this technique applied to problems of human image processing. Most theories of visual functioning cannot explain common illusions. An example is the Poggendorff illusion:



Although the two diagonal line segments fall on the same plane, they seem to be offset. By transforming a sketch of this illusion, retaining only the low frequency information, and again using a two-octave bandpass filter, the illusion can be explained. Direct measurements on the reconstructed version of the sketch show the line segments to be represented as offset. This has important consequences for understanding human visual processing. It seems that people typically use a two-octave wide band of low-frequency information in analyzing a visual scene. High-frequency, i.e., fine detail, information is much less salient.

Fourier analysis has also been applied successfully to alphanumeric symbol discrimination. The FFT technique provides a straightforward measure of the visual similarity among letter characters. This measure can be used to predict human performance on discrimination tasks, and in fact the FFT computer measure of similarity provides a better prediction of human visual discrimination performance than does a measure based on ratings of similarity by human subjects. This is an extremely important result. Similarity measures derived from subject ratings are very expensive and time-consuming to obtain. The FFT measure is not only inexpensive and fast but also provides a better predictor of performance.

The following experiment by Ginsburg (1978) illustrates the use of Fourier analysis in the context of letter discrimination. Snellen eye-chart letters were digitized and entered into the FFT program. The transformed representations of the letters were then compared pair-wise. For each pair, a correlation-like measure of similarity was calculated. This measure was compared to a measure derived from subject ratings and to actual performance on a discrimination, or confusability task. The FFT measure could account for 90% of the discrimination data, far more than the subject rating measure was able to predict.

As the preceding experiments suggest, it is now possible to identify the fundamental components (spatial frequencies) of a visual form. In addition, psychophysical experiments conducted over the past ten years (Cornsweet, 1970) have also established the visual sensitivity function illustrated in Figure F-1. This figure depicts the contrast sensitivity for each spatial frequency component and shows that the human visual system "filters" (is less sensitive) to both high and very low frequencies. The visual sensitivity function changes depending on whether a scene is viewed centrally (foveally) or peripherally.

When an image is focused on the fovea, the eye is most sensitive to frequencies between 3 and 5 cycles per degree. When the image is focused in the periphery, the eye is most sensitive to still lower frequencies (1 cycle/degree and less, depending on how far into the periphery one goes).

The verbal labels given to certain aspects of a visual scene can be defined more precisely using Fourier components. What is often called "form" in vision is the information contained in the low frequency Fourier components. What is called "detail" is the information contained in the high frequency components. For instance, a face can be recognized as a face when the only describable information to be seen is the shape of the head and the existence of eyes, nose, and mouth. This information resides in the lower frequency Fourier components. Form is a crucial

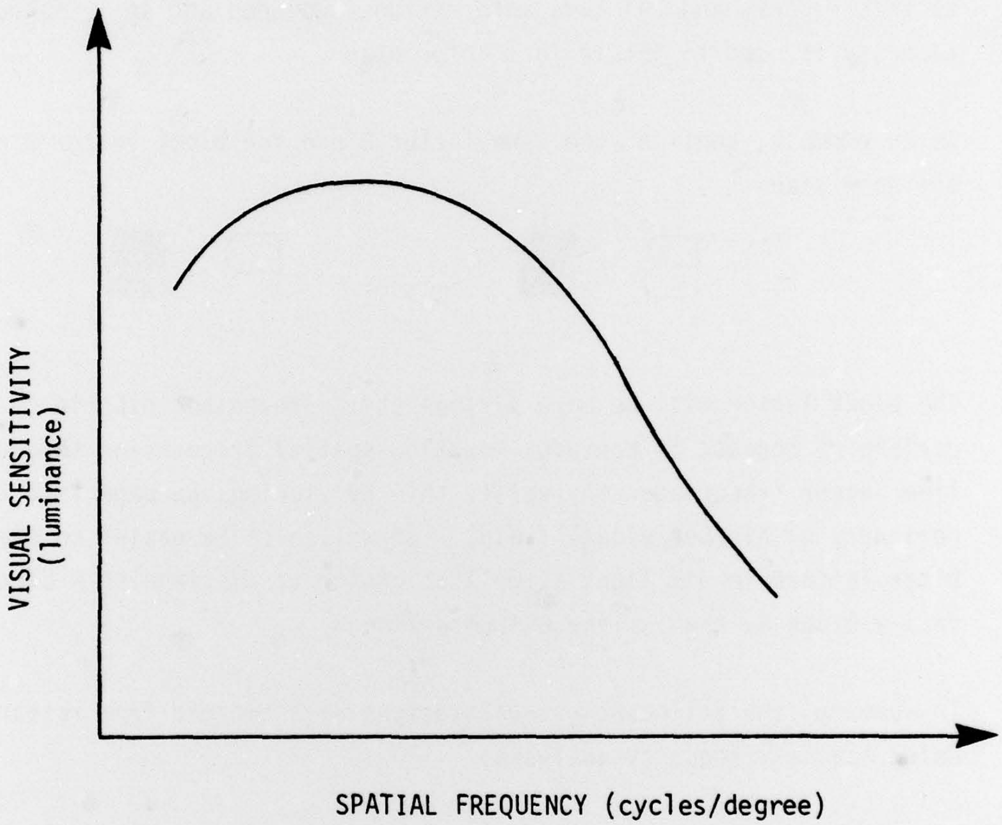


FIGURE F-1. SENSITIVITY OF THE VISUAL SYSTEM TO STIMULI OF DIFFERENT SPATIAL FREQUENCIES VIEWED FOVEALLY (ADAPTED FROM CORNSWEET, 1970).

aspect of a visual scene for three reasons: (1) it can be detected both centrally and peripherally, (2) it can be detected at both high and low contrast levels (development of this fact is not relevant to this report) and (3) less information is needed and so less processing capacity is used to obtain form information.

As an example, consider the line letter B and the block letter B of the same size:

B **B** R **R**

The block letter will be more visible at the fovea and especially in the periphery, because it contains more low spatial frequencies than does the line letter (the reader may verify this by viewing the page from the periphery of his/her visual field). It will also be easier to see the block letters in dim light as well as easier to distinguish a block B from a block R, than a line B from a line R.

In summary, the following generalizations have emerged from research using spatial frequency analysis:

(1) The human visual system is most sensitive to low spatial frequencies carrying "form" information (Cannon, 1977).

(2) High spatial frequencies convey "detail" information (thin lines and sharp edges) and these have the lowest sensitivity.

(3) Fourier components with horizontal and vertical orientations are relatively more detectable than those with oblique orientations (Dodwell, 1970).

(4) As one moves away from the foveal region, the sensitivity of low frequencies becomes greater relative to that of high frequencies (although all frequencies decrease in sensitivity). This means that peripheral vision is primarily sensitive to form information.

Using Fourier Analysis in Symbol Design Research. Fourier analysis appears to provide a powerful research tool for identifying the spatial frequency components of symbol design candidates. By analyzing each design into its constituent visual features, this technique can be used to obtain an accurate measure of:

(1) The detectability of symbols and their visual components in all portions of the visual field.
(2) The discriminability or confusability among symbols.
(3) The minimum level of perceptual detail and resolution required for perceptually effective battlefield displays.
(4) The perceptual components of display clutter.

In sum, the Fourier method can be used to identify the perceptual strengths and weaknesses of actual symbol designs.

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